DOCUMENT RESUME

ED 086 441 SE 013 875

TITLE	Nondestructive Testing Magnetic Particle RQA/M1-5330.11.
INSTITUTION	General Dynamics, San Diego, Calif. Convair Div.; National Aeronautics and Space Administration, Huntsville, Ala. George C. Marshall Space Flight Center.
REPORT NO	NAS8-20185
PUB DATE	1 Jan 67
NOTE	410p.
EDRS PRICE	MF-$0.65 HC-$16.45
DESCRIPTORS	Aerospace Technology; *Instructional Materials; Magnets; Post Secondary Education; *Programed Instruction; Quality Control; *Reading Materials; Science Education; *Technical Education

ABSTRACT

As one in the series of programmed instruction handbooks, prepared by the U. S. space program, home study material is presented in this volume concerning familiarization and orientation on magnetic particle properties. The subject is presented under the following headings: Magnetism, Producing a Magnetic Field, Magnetizing Currents, Materials and Sensitivity, Magnetic Particle Indications, Inspection Methods, and Demagnetization. High product reliability and quality in metal processing are the main concerns throughout the volume. The material is designed for use with formal courses and written in a scrambled, self-study, self-pacing format including self-test questions. Learners are instructed when to turn the book around and read the upside-down printed pages. "Linear review" frames are provided at various points to help learners in reviewing the preceding material. Beside illustrations for explanation purposes, a self-test answer sheet is included. (CC)

FILMED FROM BEST AVAILABLE COPY

ED 086441

January 1, 1967

QUALITY AND
RELIABILITY ASSURANCE
LABORATORY

U S DEPARTMENT OF HEALTH,
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION
THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

NONDESTRUCTIVE TESTING
MAGNETIC PARTICLE
RQA/M1-5330.11

GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SE 013 895

MSFC - Form 1262 (September 1963)

WHAT IS PROGRAMMED INSTRUCTION

Programmed instruction is intended to accomplish two important tasks. When used--

> For home study
> It will enable the student to learn basic principles of the NDT method at his own pace and without the need for formal classroom sessions.
>
> As a prerequisite -
> It will bring all students together in the formal school with the same basic knowledge of the subject, thus permitting the instructor to spend a maximum amount of time on the practical aspects of the method and in giving the students actual practice.

Now, what is programmed instruction? Briefly, it is a teaching technique in which the learner is given a series of carefully sequenced statements (frames) that build little by little from a simple start to a more complex goal. This, in itself, is not necessarily new (although we have all seen textbooks that could be improved in this respect). The unique feature of programmed instruction, or P. I., as it is usually called, is that the student is constantly called upon to make a decision or exercise judgement as he progresses. A correct decision means he has learned the point being taught and he is given new material to absorb. A wrong choice or decision exposes him to additional material before he is sent on to the next point. This keeps things interesting for the student. He is immediately informed of the correctness of his choice. If he is right, it provides more incentive to go on. If he is wrong, he is immediately corrected and in this way does not fall so far behind that he gets discouraged (as so often happens in a conventional classroom situation).

The P. I. approach is also self-pacing. The learner is under no obligation to maintain an artificial pace established by class scheduling. The fast student is not held back and the slow student is not pushed beyond his ability to properly absorb the material.

Here are some things you should know about the program.

1. The sequence of material often found in a conventional textbook does not always lend itself to a programmed approach. In P. I., one fact must lead to another and each new fact should have the necessary foundation. For this reason, you may find spots that appear incomplete. If so, be patient - you will probably find the complete thought developed in later frames.

2. Repetition is a way of life in P. I. This is part of the learning process that is built into the program.

3. At various points throughout the program you will find "linear review" frames. These require the active participation of the student by requiring him to write in key words or statements that review the preceding material. This is another part of the learning process.

4. The program is intended to teach only the basic concepts of the process. It is recognized that there are many refinements, advanced techniques, specialized equipment, etc., that are not taught. Some of these will be learned during formal classroom periods and laboratory exercises. Others will be learned by experience only.

5. To you who are familiar with the subject, the material may appear to be unnecessarily simple in places. This was done purposely to prevent a student, to whom the subject is completely new, from becoming overwhelmed and discouraged by a sudden mass of technical material. Remember, familiarity makes the subject very simple to you, but to the beginner, it's like a new language.

6. Finally, there is no intention of making the student a polished NDT technician by means of the P. I. program. He still has a long way to go as you know. The P. I. handbooks will give him certain basics. The classroom will refine and expand this material. His practice sessions at an NDT school will further familiarize him with equipment and techniques. But, he will still need considerable experience before he can exercise that keen judgement that comes through months and years of actual exposure to the many variations and problems that can arise.

TABLE OF CONTENTS

Preface ii

Acknowledgment iv

Introduction. v

Instructions. vi

Chapter 1 - Magnetism 1-1

- Theory 1-1
- Magnetic Particle Test Principles 1-15

Chapter 2 - Producing a Magnetic Field 2-1

- Circular Magnetic Field. 2-10
- Longitudinal Magnetic Field 2-55
- Magnetization by Cable 2-71
- Use of Prods. 2-75
- Use of a Yoke 2-80

Chapter 3 - Magnetizing Currents 3-1

- Alternating Current (ac). 3-1
- Direct Current (dc) 3-2
- Half-wave Direct Current (HWDC) 3-2
- Current Requirements (Circular Magnetization) 3-24
- Current Requirements (Longitudinal Magnetization) 3-37

Chapter 4 - Materials and Sensitivity 4-1

- Sensitivity of Methods 4-11

Chapter 5 - Magnetic Particle Indications 5-1

- Nonrelevant Indications 5-23
- Elimination of Nonrelevant Indications 5-51
- False Indications 5-52

Chapter 6 - Inspection Methods 6-1

- Wet Continuous-field Method 6-1
- Dry Continuous-field Method 6-8
- Residual-field Method 6-14
- Magnetic Particle Inspection Limitations 6-21
- Safety Precautions. 6-25

Chapter 7 - Demagnetization 7-1

- Theory 7-1
- Demagnetization Procedures 7-26
- Leakage Field Indicators 7-49

PREFACE

Programmed Instruction Handbook - Magnetic Particle Testing (5330.11) is home study material for familiarization and orientation on Nondestructive Testing. This material was planned and prepared for use with formal Nondestructive Testing courses. Although these courses are not scheduled at this time the material will be a valuable aid for familiarization with the basics of Nondestructive Testing. When used as prerequisite material, it will help standardize the level of knowledge and reduce classroom lecture time to a minimum. The handbook has been prepared in a self-study format including self-examination questions.

It is intended that handbook 5330.9, Introduction to Nondestructive Testing, be completed prior to reading other Programmed Instruction Handbooks of the Nondestructive Testing series. The material presented in these documents will provide much of the knowledge required to enable each person to perform his Nondestructive Testing job effectively. However, to master this knowledge considerable personal effort is required.

This Nondestructive Testing material is part of a large program to create an awareness of the high reliability requirements of the expanding space program. Highly complex hardware for operational research and development missions in the hazardous and, as yet, largely unknown environment of space makes it mandatory that quality and reliability be developed to levels heretofore unknown. The failure of a single article or component on a single mission may involve the loss of equipment valued at many millions of dollars, not to mention possible loss of lives, and the loss of valuable time in our space timetable.

A major share of the responsibility for assuring such high levels of reliability, lies with NASA, other Government agencies, and contractor Nondestructive Testing personnel. These are the people who conduct or monitor the tests that ultimately confirm or reject each piece of hardware before it is committed to its mission. There is no room for error -- no chance for reexamination. The decision must be right -- unquestionably -- the first time. This handbook is one step toward that goal.

General technical questions concerning this publication should be referred to the George C. Marshall Space Flight Center, Quality and Reliability Assurance Laboratory, Huntsville, Alabama 35812.

The recipient of this handbook is encouraged to submit recommendations for updating and comments for correction of errors in this initial compilation to George C. Marshall Space Flight Center, Quality and Reliability Assurance Laboratory (R-QUAL-OT), Huntsville, Alabama 35812.

ACKNOWLEDGMENTS

This handbook was prepared by the Convair Division of General Dynamics Corporation under NASA Contract NAS8-20185. Assistance in the form of process data, technical reviews, and technical advice was provided by a great many companies and individuals. The following listing is an attempt to acknowledge this assistance and to express our gratitude for the high degree of interest exhibited by the firms, their representatives, and other individuals who, in many cases, gave considerable time and effort to the project.

Aerojet-General Corp.; Automation Industries, Inc., Sperry Products Division; AVCO Corporation; The Boeing Company; Douglas Aircraft Co., Inc.; Grumman Aircraft; Lockheed Aircraft Co.; Magnaflux Corp.; The Martin Co. (Denver); McDonnell Aircraft Corp.; North American Aviation, Inc.; Rohr Corporation; Southwest Research Institute; St. Louis Testing Laboratories, Inc.; Uresco, Inc.; X-Ray Products Corp.

Our thanks is also extended to the many individuals who assisted in the testing of the materials to validate the teaching effectiveness. Their patience and comments contributed greatly to the successful completion of the handbook.

INTRODUCTION

Magnetic Particle Testing is one of the more common methods of nondestructive testing in use today. It was first used on a large scale in the years immediately preceding World War II. Since that time, the techniques and equipment have been further developed and refined until today the speed and sensitivity of the method makes it practically indispensable for some applications.

In this handbook, we will discuss magnetism, typical equipment, indications, and how to remove the magnetic field from a magnetized article. The level of discussion is relatively simple. It is not intended that the reader receive an engineering background in the subject, only that he learn enough theory and receive enough practical instruction that when he is exposed to the actual task of performing magnetic particle testing, he will understand the process.

The material is presented in one volume.

Prior to reading this handbook, the reader should have completed 5330.9, Introduction to Nondestructive Testing.

INSTRUCTIONS

The pages in this book should not be read consecutively as in a conventional book. You will be guided through the book as you read. For example, after reading page 3-12, you may find an instruction similar to one of the following at the bottom of the page -

- Turn to the next page
- Turn to page 3-15
- Return to page 3-10

On many pages you will be faced with a choice. For instance, you may find a statement or question at the bottom of the page together with two or more possible answers. Each answer will indicate a page number. You should choose the answer you think is correct and turn to the indicated page. That page will contain further instructions.

As you will soon see, it's very simple - just follow instructions.

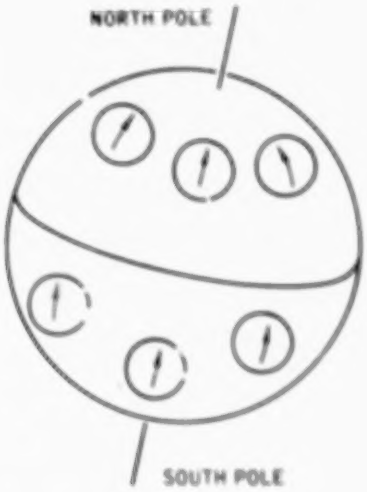
As you progress through the book, ignore the back of each page. THEY ARE PRINTED UPSIDE DOWN. You will be instructed when to turn the book around and read the upside-down printed pages.

TURN TO THE NEXT PAGE

Theory

Magnetic particle testing is a nondestructive test method for detecting discontinuities in materials that can be highly magnetized. To more fully appreciate the details of how the magnetic particle test functions, let us first study magnetic field theory.

Magnetism is the ability of some metals, mainly iron and steel, to attract other pieces of iron and steel. Consider the ordinary magnetic compass which is simply a magnetized steel pointer. When the pointer is allowed to rotate freely, it will always point in the same direction because it is attracted by the earth's magnetic field.

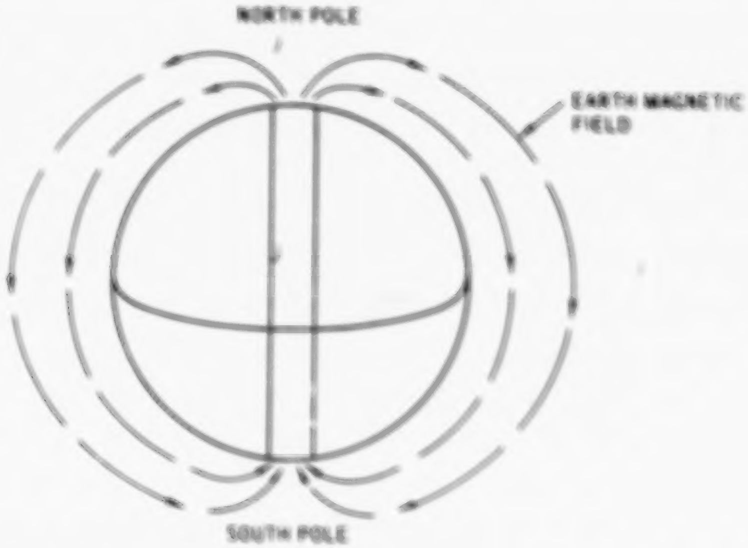


Observe that the compass needle points to the earth's north pole from any point on the earth's surface. Every magnet has a north and south pole.

Turn to the next page.

From page 1-1

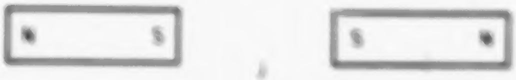
Now, consider the earth as a giant magnet and you can see why the magnetic compass acted as it did.



The magnetic compass acted as it did because of the earth's magnetic field. The compass needle, being magnetized, was attracted to the earth's poles. The rule of magnetic attraction and repulsion for magnets is:

LIKE MAGNETIC POLES REPEL AND UNLIKE MAGNETIC POLES ATTRACT ONE ANOTHER

Using this rule, we know that if two magnets are placed so that a south pole of one is placed close to the north pole of the other, the magnets will be attracted to each other. What would happen if the magnets are placed like this?

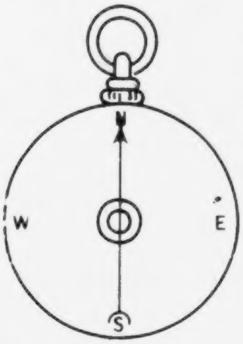


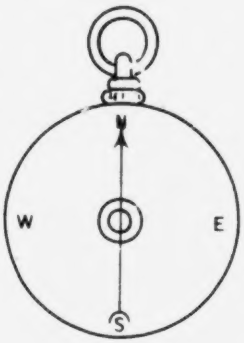
Select the correct statement and turn to the page indicated.

The magnets would attract each other . . . . Page 1-3
The magnets would repel each other . . . . Page 1-4

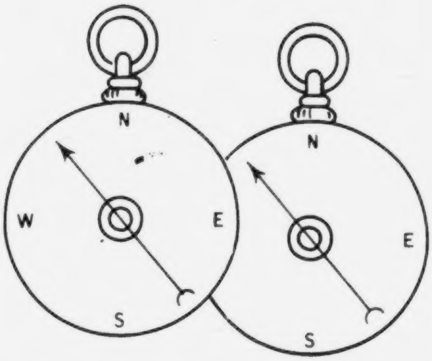
From page 1-2

You selected--The magnets would attract each other. Perhaps we've confused you by not telling you what we mean by "like poles." Consider a compass needle. A compass needle will point toward the earth's north pole. The end of the needle that points to the earth's north pole is called the north pole of the needle. The other end of the needle points south and is called the south pole. Here are two compasses.





If we bring the two compasses close together, the needles will no longer point to the earth's north pole. The north pole of one needle will attract the south pole of the other like this.



Here you can see the UNLIKE (north and south) poles are attracting one another. Two south poles would repel each other.

Turn to page 1-4.

From page 1-2

Right. If the magnets were placed so that the south poles were close together, they would repel each other. Here is the rule again.

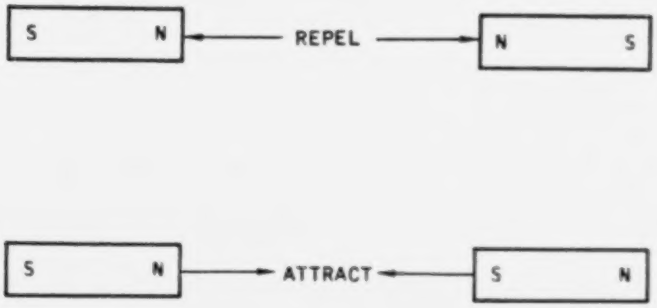
> LIKE MAGNETIC POLES REPEL EACH OTHER. UNLIKE MAGNETIC POLES ATTRACT EACH OTHER.

Here are two magnets without their poles identified.

You can see that these magnets have attracted each other to the point of contact. Which of the following combinations of poles must exist for the magnets to attract each other?

Two south poles . . . . Page 1-5
A south and a north pole . . . . Page 1-6
Two north poles . . . . Page 1-7

Not exactly. A south pole will repel another south pole. They will tend to push away from one another because they are like poles.



Let's look at the rule again.

> LIKE MAGNETIC POLES REPEL EACH OTHER. UNLIKE MAGNETIC POLES ATTRACT EACH OTHER.

Return to page 1-4 and select another alternative.

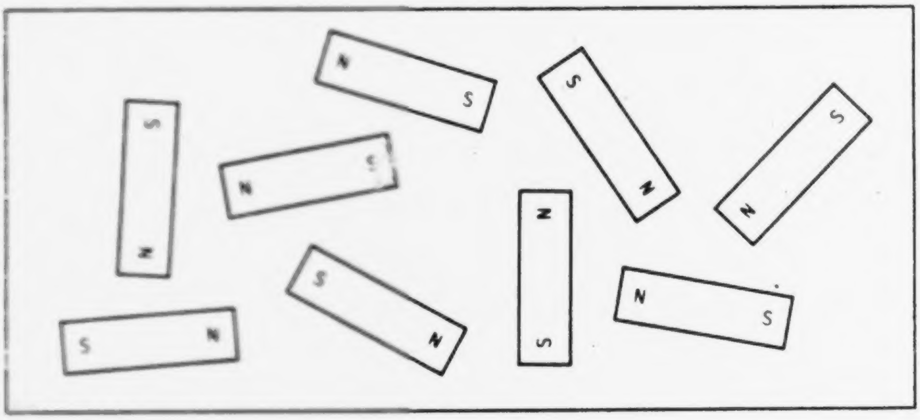
From page 1-4

Right again. The two magnets were attracted to each other because UNLIKE POLES ATTRACT EACH OTHER. A south pole of one magnet was attracted by the north pole of the other magnet.

Now let's take a deeper look at the reasons why magnets act as they do.

Just as the earth itself is a large magnet having a north and south pole, every molecule of matter is also a small magnet having a north and south pole. Each molecule of matter is also a small magnet having a north and south pole. Each molecule sets up its individual field of force due to the atom structure within the molecule.

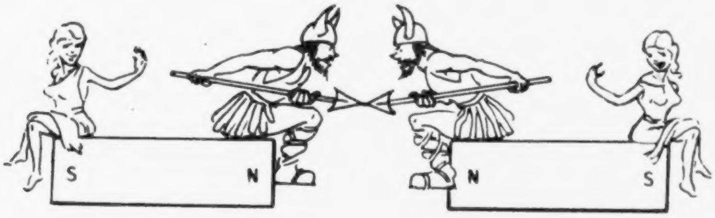
In an unmagnetized piece of iron, the molecules are arranged in a haphazard fashion like this.



Now if all of the molecules in the above piece of iron were lined up in an organized manner, the piece of iron would be a magnet.

Turn to page 1-8.

No. A north pole will repel another north pole. They will tend to push away from one another because they are "like poles."

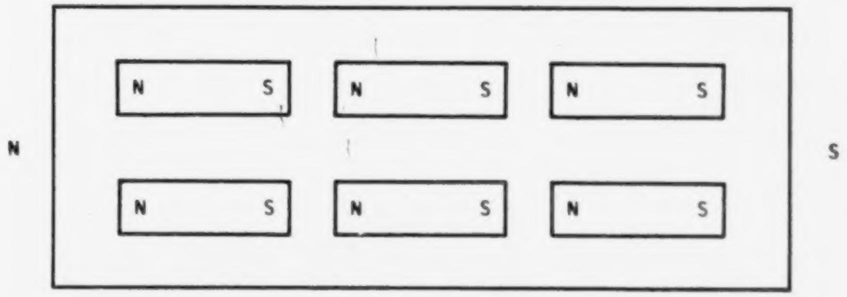


Here is the rule again.

> LIKE MAGNETIC POLES REPEL EACH OTHER. UNLIKE MAGNETIC POLES ATTRACT EACH OTHER.

Return to page 1-4 and select another answer.

Now, in a manner which will be discussed later, let's magnetize this same piece of iron. When the iron is magnetized, each molecule of the iron is magnetized so that all north poles are oriented in one direction and all of the south poles are oriented in one direction



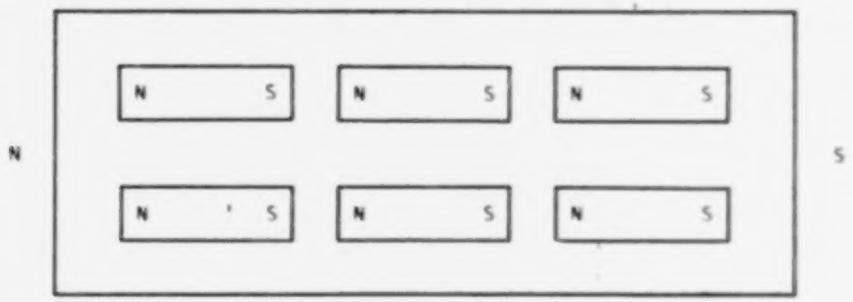
With all of the molecules magnetized like this, the piece of iron then has a north and south pole.

Since the molecules are now magnetized so that the north pole of one molecule is facing the south pole of the next molecule, what rule of magnetism is taking place within the bar?

Unlike magnetic poles repel each other . . . . Page 1-9

Unlike magnetic poles attract each other . . . . Page 1-10

You say that unlike magnetic poles repel each other. Look at the bar again.

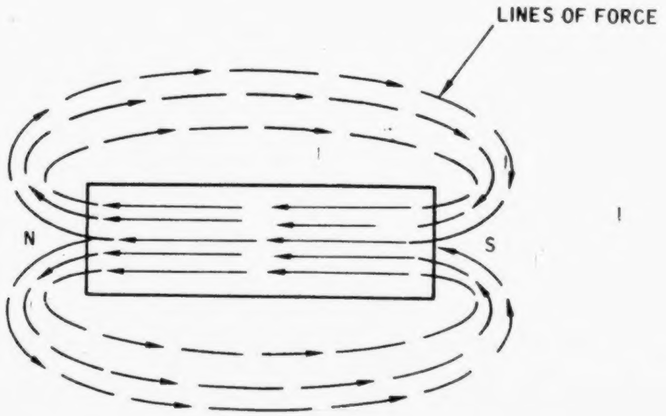


In this case, we have the south pole of one molecule facing the north pole of another molecule. When we have a situation like this, the molecules attract each other. UNLIKE MAGNETIC POLES ATTRACT EACH OTHER.

Turn to page 1-10.

Good for you. That's right. Unlike poles attract each other. Since a north pole was facing a south pole, both poles were attracted to each other.

With all of the molecules lined up this way, the magnetic bar developes a total force equal to the sum of all of the molecules. This is what we have now.



These are magnetic lines of force which surround every magnet. These lines of force have a definite direction. They leave their north pole and re-enter their south pole and continue on their way through the magnet from the south pole to the north pole.

Magnetic lines of force are continuous and always form a closed loop or circuit. The individual lines of force do not cross or merge with other lines of force.

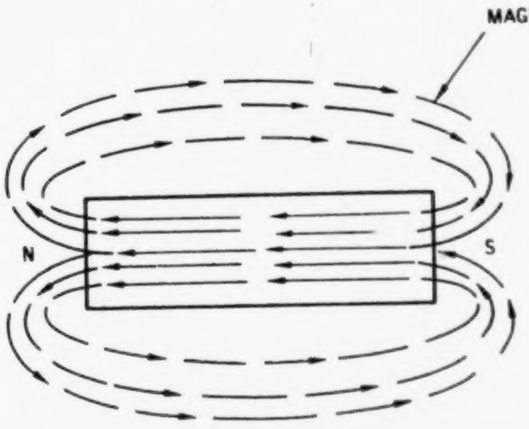
Considering the direction the lines of force take around a magnet, which of the following statements is true?

Lines of force follow a path to an opposite pole . . . . Page 1-11
Lines of force follow a path to a like pole . . . . Page 1-12

From page 1-10

Right. Lines of force around a magnet follow a path to an opposite pole.

The space around a magnet in which the lines of force act is called the MAGNETIC FIELD.



There are many lines of force surrounding a magnet. All of the lines of force make up the MAGNETIC FIELD.

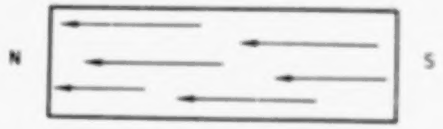
Based on the above, which of the following statements is correct?

All magnetic lines of force around a magnet are contained within the magnetic field . . . . Page 1-13

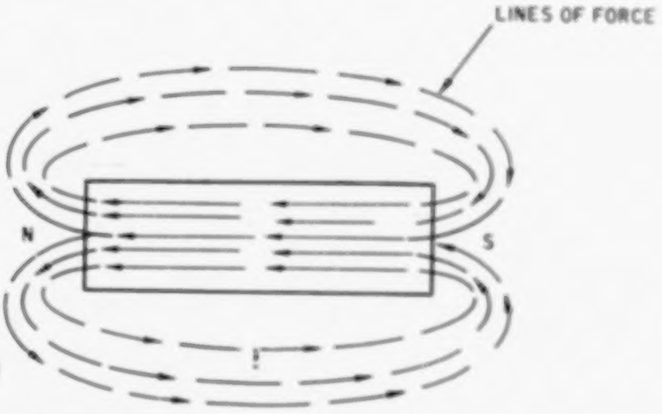
Magnetic lines of force around a magnet are found both inside and outside the magnetic field . . . . Page 1-14

From page 1-10

You feel that lines of force follow a path to like poles. Let's look at this from a different angle. Here is a magnet with the lines of force going from the south pole to the north pole within the magnet.



Now, let's add the external lines of force.



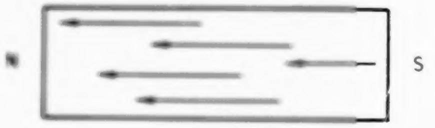
As you can see, in both cases, the lines of force always follow a path to an opposite pole.

Turn to page 1-11.

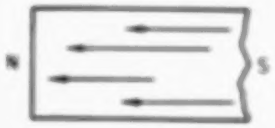
From page 1-11

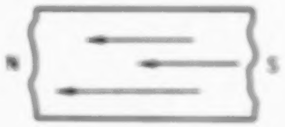
That's right. All magnetic lines of force around a magnet are contained within the magnetic field.

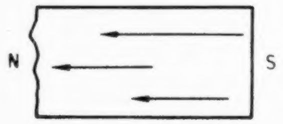
Now let us look at our magnet without the external lines of force.



Here, you can see the lines of force within the magnet flowing from the south pole to the north pole. Let's break the magnet into several pieces.







When the bar magnet is broken into several pieces, each piece becomes a complete magnet within itself with a north and south pole and lines of force. If we continue to break the bar into more pieces, each piece will have a north pole and a south pole.

Turn to page 1-15.

From page 1-11

You weren't thinking on this one. It is impossible to have any magnetic lines of force outside the magnetic field since the magnetic lines of force are the magnetic field.

ALL MAGNETIC LINES OF FORCE AROUND A MAGNET ARE CONTAINED WITHIN THE MAGNETIC FIELD.

Turn to page 1-13.

From page 1-13

MAGNETIC PARTICLE TEST PRINCIPLES

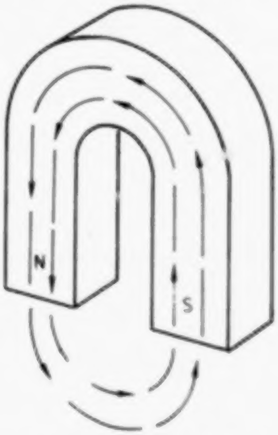
In discussing the Theory of Magnetism, we found that every magnet has a north and a south pole. We found that every magnet also has a magnetic field comprised of the lines of force.

Here, we are going to discuss these terms as they apply to the principles of magnetic particle testing.

In all magnets, the lines of force flow from the south pole to the north pole. The force that attracts other magnetizable materials to the magnetic poles is known as MAGNETIC FLUX. Magnetic flux is made up of all the lines of force.

First, let us study the nature of the lines of force in magnets of different shapes.

The most common magnet is the horseshoe magnet.



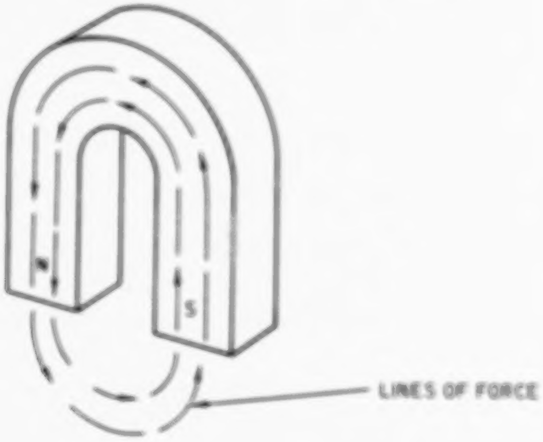
In the horseshoe magnet, the magnetic flux or lines of force will enter or leave the magnet at the poles. The horseshoe magnet will attract other magnetizable material only where the lines of force LEAVE OR ENTER the magnet.

If we were to dip the horseshoe magnet into a bucket of iron filings, where could we expect magnetic flux to attract the filings?

At the north pole	Page 1-16
Anywhere on the magnet	Page 1-17
At the north and south poles	Page 1-18

You are half right. Iron filings would be attracted to the north pole. That is because the lines of force leave the magnet at the north pole.

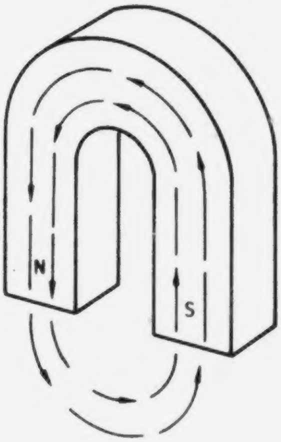
In the horseshoe magnet, the magnetic lines of force or flux will enter or leave the magnet at the poles.



The horseshoe magnet will attract other magnetic materials only where the lines of force LEAVE or ENTER the magnet.

Return to page 1-15 and try one of the other answers.

You selected--anywhere on the magnet. You have missed the key words. Magnetizable material will be attracted to the horseshoe magnet ONLY WHERE THE LINES OF FORCE LEAVE OR ENTER THE MAGNET.

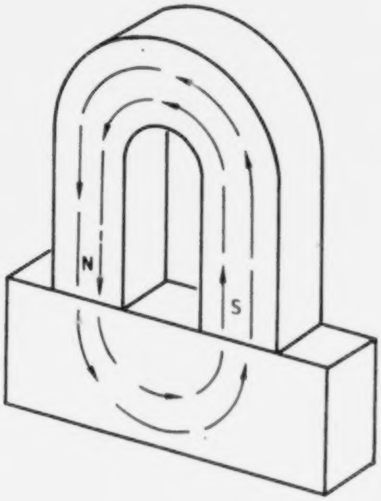


In the metal portion of this magnet, the magnetic field is contained entirely within the metal. The lines of force go from the south pole to the north pole and do not leave the magnet between these points. At the north pole, the lines of force leave the magnet. These lines of force are attracted by the south pole where they re-enter the magnet. Since materials like iron filings will be attracted to the magnet where the lines of force leave or enter the magnet, iron filings will be attracted only to the north and south poles of the magnet.

Return to page 1-15 and choose another answer.

From page 1-15

Right. If we dip the horseshoe magnet into a bucket of iron filings, the magnetic flux would attract iron filings to both the north and south poles. Why? Because a horseshoe magnet will attract other magnetizable material ONLY where the MAGNETIC FLUX (lines of force) leave or enter the magnet.



Here, a steel bar has been placed across the poles of the magnet. It is held in place by the attracting force of the magnetic flux.. The magnetic flux lines flow from the north pole of the magnet, through the steel bar to the south pole of the magnet.

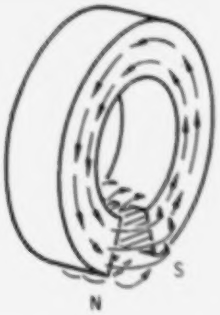
If the steel bar were placed across only the north pole, would it be attracted to the horseshoe magnet?

Yes . . . . Page 1-19
No . . . . Page 1-20

That's right. If the steel bar were placed across only the north pole, it would be attracted to the magnet because the magnetic flux lines leave the magnet at the north pole. If the steel bar had been placed over the south pole it would also have been attracted since that is where the lines of force enter the magnet.

Actually, we can say that iron and steel will be attracted to the poles of a magnet.

Suppose we bend the horseshoe magnet so the north and south poles are close together.

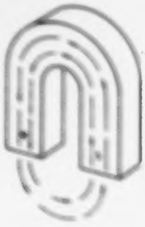


In the circular magnet, the lines of force also flow from the south pole to the north pole. Where would iron or steel be attracted to this circular magnet?

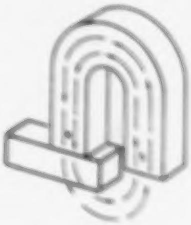
Nowhere on the magnet . . . . Page 1-21

At the poles . . . . Page 1-22

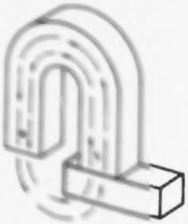
You feel that the bar would not be attracted at the north pole. You must have forgotten that magnetic materials will be attracted to the magnet at the points where the lines of force ENTER OR LEAVE the magnet. Here, you can see the lines of force leaving the magnet at the north pole and entering the magnet at the south pole.



The steel bar will be attracted to the north pole.



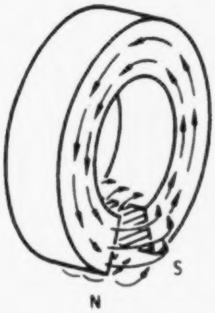
The steel bar will also be attracted to the south pole.



The steel bar will be attracted to either pole because these are the places where the lines of force enter and leave the magnet. Right?

Turn to page 1-19.

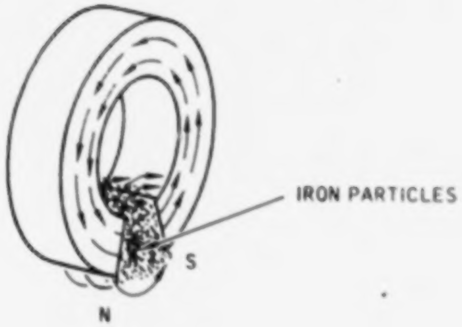
You feel that iron and steel would not be attracted anywhere on the magnet. Most of the circular magnet will not attract iron or steel. But we still have the poles where the lines of force enter and leave the magnet.



Although we did change the shape of the magnet, we did not change the fact that there are two magnetic poles. As you can see above, the lines of force are leaving the magnet at the north pole and entering the magnet at the south pole. Iron or steel would be attracted to these poles.

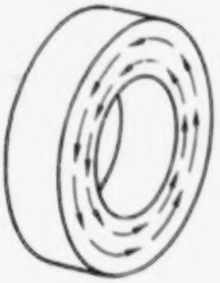
Turn to page 1-22.

Good for you. That's right. Iron and steel would be attracted at the poles.



Here you can see the iron particles clinging to the poles and bridging the gap between the poles.

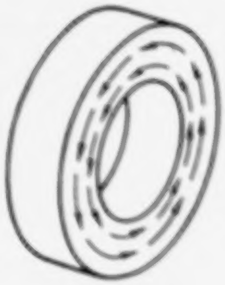
Now, let us make a complete circle out of the magnet and see what happens.



Here is a complete-circle magnet without any poles. The lines of force, or flux, are contained entirely within the circle. If we dust iron particles on this magnet, where would they be attracted to the magnet.

Iron particles would be attracted to all points on the magnet	Page 1-23
Iron particles would not be attracted to the magnet	Page 1-24

Watch out. Did you see any magnetic poles on that complete circle magnet? Remember, iron particles will be attracted to the magnet ONLY where lines of force, or flux,

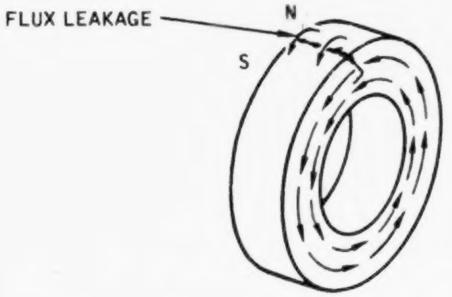


enter or leave the magnet. Since there are no magnetic poles, there will be no place for the magnetic lines of force or flux to leave or enter the magnet.

Turn to page 1-24.

Excellent. That's right. Iron particles would not be attracted to the magnet at all. Since the circle magnet has all of the lines of force contained within the magnet, there is no place where the lines of force, or flux, can enter or leave. In other words, there are no poles.

Let us now take a look at the complete circle magnet with a crack in the outer surface and see what happens.



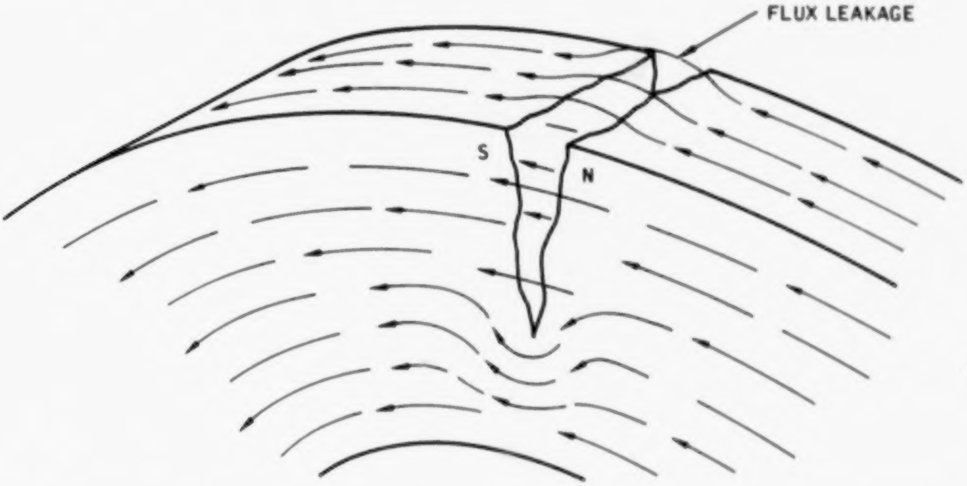
A crack in the magnet will disrupt the even flow of the lines of force. Some of the lines of force will be forced out of the magnet. This creates a magnetic field with a north and south pole. The lines of force that are forced out of the magnet as a result of the crack are known as FLUX LEAKAGE.

Since the crack in the circular magnet has created a north and south pole, what would you expect to occur where the flux leakage is located?

Iron particles would not be attracted . . . . Page 1-25

Iron particles would be attracted . . . . Page 1-26

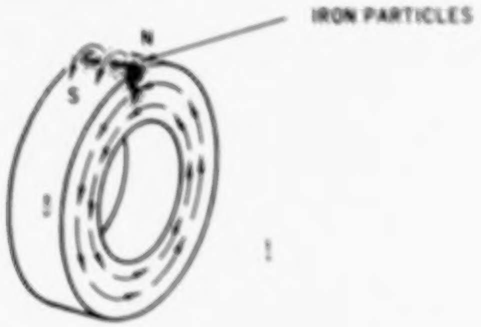
You feel that iron particles would not be attracted at the flux leakage. Let's explain a little more fully what is happening. Here is an enlarged view of the crack in the circular magnet.



The crack runs crosswise to the lines of force. At the crack, the lines of force jump through the crack causing a north and south pole. Some of the lines of force are forced to jump over the crack and they do this because they are following the path of least resistance. The lines of force that jump through and over the crack are known as flux leakage. The flux leakage attracts iron particles.

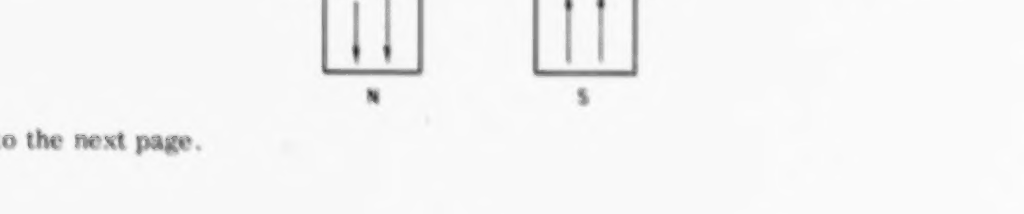
Turn to page 1-26.

Correct. You would expect iron particles to be attracted at the crack where flux leakage is located. The iron particles would be attracted to the poles created by the crack. Here is the cracked magnet again.



Here, you can see that the iron particles have been attracted by the FLUX LEAKAGE created by the crack.

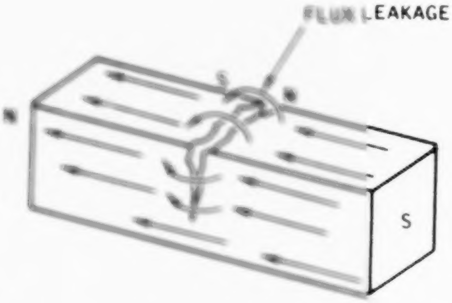
Now let us go back to the horseshoe magnet. If we straighten the horseshoe magnet, we have a BAR MAGNET.



Turn to the next page.

The bar magnet has the same characteristics as the horseshoe magnet. The lines of force, or flux, flow from the south to the north pole. Iron particles will be attracted only to the poles where the lines of force, or flux, leave and enter the magnet.

A crack in a bar magnet will also cause FLUX LEAKAGE.



The lines of force at the bottom of the crack tend to follow the line of least resistance and remain in the magnet. The lines of force passing through the area of the crack tend to be forced to the surface. Some of the lines of force bridge the gap and jump through the crack, while others are forced to the surface where they jump over the crack. These lines of force that jump through and over the crack cause flux leakage and north and south poles in the vicinity of the crack.

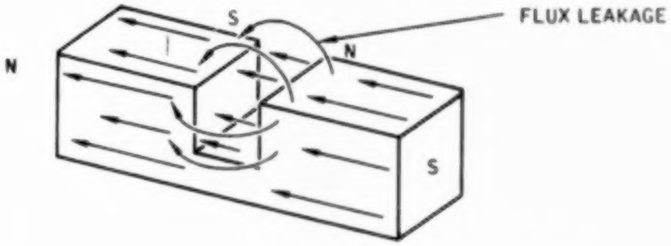
Do you think iron particles would be attracted at the flux leakage created by the crack?

Yes . . . . Page 1-28

No . . . . Page 1-29

Excellent. Of course iron particles would be attracted at the flux leakage created at the crack.

If we had a bar magnet with a slot cut into it like this one, we also have FLUX LEAKAGE.



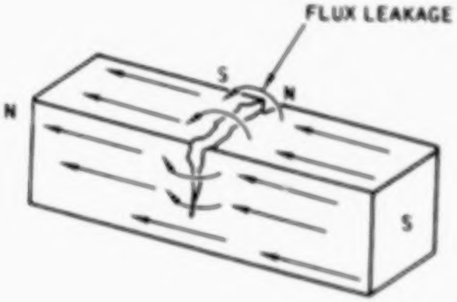
Here you can see the magnetic poles and flux leakage created by the slot. The lines of force in the vicinity of the slot tend to be forced toward the surface. Some of the lines of force jump through the slot, while others are forced to the surface where they jump over the slot.

If we add two more slots to the above magnet, do you think each would create flux leakage?

No . . . . Page 1-30

Yes . . . . Page 1-31

You have missed the point. Let's look at that diagram again.

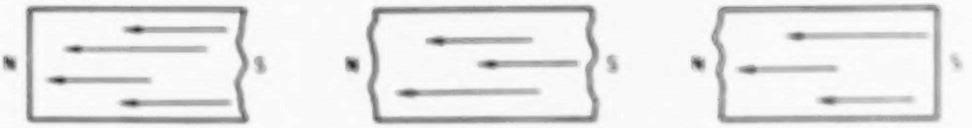


Review these Facts:

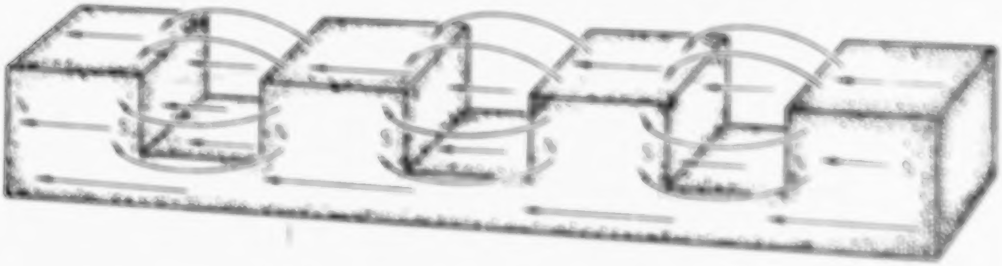
1. We have a magnetized bar (bar magnet).
2. The lines of force pass through the bar.
3. The lines of force are interrupted by the crack causing FLUX LEAKAGE.
4. Magnetic poles are formed at the crack.
5. Iron particles will be attracted by the FLUX LEAKAGE at the magnetic poles formed at the crack.

Turn to page 1-28.

Evidently we haven't made the point clear. Let's go back to the example of the broken magnet.



When the bar magnet is broken into several pieces, each piece becomes a complete magnet within itself with a north and south pole and lines of force. The same thing happens to the bar magnet if we cut slots in it.



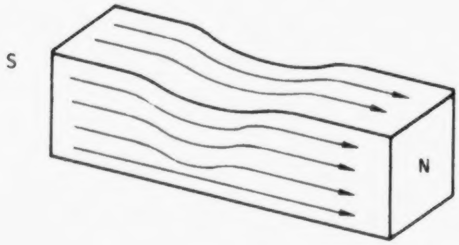
If we cut three slots in the bar, a north and south pole will be created at each slot. We will also have flux leakage at each of the slots as shown above.

Turn to page 1-31.

Yes sir. Each slot that we put into that magnet would create flux leakage. Iron particles would be attracted to the flux leakage.

On any magnet, materials like iron and steel will be attracted to the poles of the magnet. If the magnet has all of the lines of force contained within the magnet as with the circular magnet, there would be no poles. Therefore, iron particles would not be attracted.

Now, let us look at a magnet with a shallow surface irregularity such as a rounded surface.



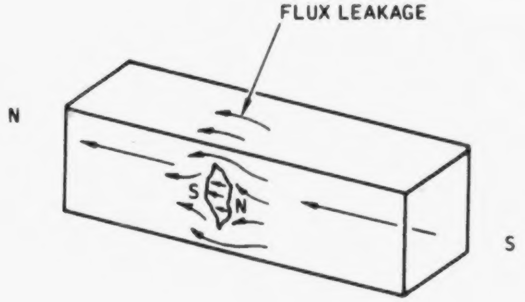
In the area of the shallow rounded surface above, the lines of force stay within the magnet. The lines of force tend to follow the path of least resistance which is to stay within the magnet. As a result, no magnetic poles with flux leakage are created.

Would iron particles be attracted to the shallow rounded surface above?

No . . . . Page 1-32
Yes . . . . Page 1-33

Of course not. There were no poles with flux leakage to attract iron particles. The lines of force followed the path of least resistance which was to follow the metal in the shallow rounded surface.

Here's another magnet with a crack located below the surface.



With this subsurface crack, you can see that some of the lines of force pass above and below the crack. Some of the lines of force jump through the crack and some are forced out at the surface creating flux leakage.

Do you think that iron particles would be attracted to the flux leakage caused by the subsurface crack?

Yes . . . . Page 1-34

No . . . . Page 1-35

From page 1-31

We caught you napping. Iron particles would not be attracted to that shallow rounded surface. Because the lines of force remained in the metal, no flux leakage was created.

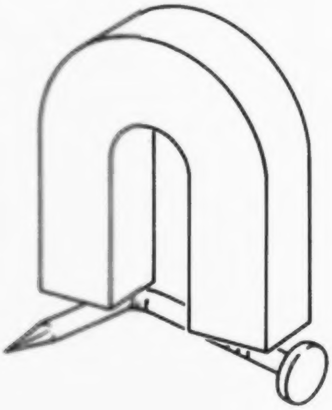
Remember, iron particles will only be attracted at points where the lines of force leave and enter the magnet. In other words, iron particles will only be attracted to flux leakage. In the example, there was no flux leakage at the shallow rounded surface so iron particles would not be attracted.

Turn to page 1-32.

That's right. Iron particles would be attracted to the flux leakage caused by the subsurface crack.

Magnetic particle test principles depend upon establishing a magnetic field within a test specimen. Therefore, the specimen to be inspected must be made of materials which can be strongly magnetized. Ferrous materials are most strongly affected by magnetism.

By definition, ferrous means, "pertaining to, or derived from, iron." Since iron can be easily magnetized, it is called ferromagnetic. Iron, steel, nickel, cobalt, and many of their alloys, are ferromagnetic materials.



If a nail can be picked up by a horseshoe magnet, what kind of material would you say the nail is made of?

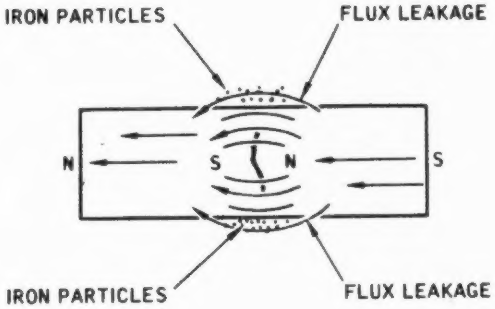
Non-magnetic material . . . . Page 1-36

Ferromagnetic material . . . . Page 1-37

From page 1-32

You have forgotten one thing: WHEREVER LINES OF FORCE ENTER OR LEAVE THE METAL, POLES WILL BE FORMED AND IRON PARTICLES WILL BE ATTRACTED TO THE FLUX LEAKAGE.

FLUX LEAKAGE will also be formed whenever a crack below the surface causes the lines of force to leave the metal.


IRON PARTICLES
FLUX LEAKAGE
N
S
N
S
IRON PARTICLES
FLUX LEAKAGE

Notice that the spot where lines of force leave the metal is not as clearly defined as it would be if there was a crack in the surface. SO, IRON PARTICLES WOULD BE ATTRACTED TO THE FLUX LEAKAGE CAUSED BY THE SUBSURFACE CRACK.

Turn to page 1-34.

Oooops, you've got it backwards. FERROMAGNETIC means--easily magnetized--attracted by magnets.

NON-MAGNETIC--not easily magnetized--not attracted by magnets.

The nail is attracted by the magnet, therefore it is ferromagnetic material.

Turn to page 1-37.

You bet. The nail would have to be ferromagnetic material in order to be picked up by the magnet. Ferromagnetic materials are those materials which are strongly attracted by a magnetic field.

Non-magnetic materials cannot be strongly magnetized. Non-magnetic materials include aluminum, brass, copper, magnesium, bronze, lead, titanium, and some stainless steels.

If a piece of wire would not stick to a horseshoe magnet, you would know that the wire was made of which kind of material?

Ferromagnetic material . . . . Page 1-38
Non-magnetic material . . . . Page 1-39

From page 1-37

A piece of wire that would not stick to a horseshoe magnet would not be ferromagnetic material.

Ferromagnetic materials will stick to a magnet. A nail is ferromagnetic because it can be picked up with a horseshoe magnet. Remember, ferrous means "of, or pertaining to, iron." Iron will be attracted to a magnet.

A piece of copper wire cannot be picked up by a magnet so the wire is called non-magnetic. Any metal that is not attracted to a magnet is non-magnetic.

Turn to page 1-39.

Right. The wire would be made of non-magnetic material.

All matter is subject to the influence of a magnetic field to some degree. In other words, they are permeable to some small degree. A few types of materials, such as bismuth, are repelled by the magnetic field. These materials are referred to as diamagnetic. Other materials which are attracted by a magnetic field are called paramagnetic. Only a few materials in this classification are strongly attracted by a magnet -- these are the ferromagnetic materials. The rest of the paramagnetic materials are commonly referred to as non-magnetic. We are concerned here only with the small group of paramagnetic materials such as iron, steel, nickel, cobalt and many of their alloys which we have labeled as ferromagnetic. We will refer to them as magnetic materials from here on.

PERMEABILITY IS DEFINED AS:

THE EASE WITH WHICH MATERIALS CAN BE MAGNETIZED.

"permeability" comes from the word "permeate" meaning "to spread through." As we are using it, permeability means the ease with which the lines of force are spread through the material.

Soft iron and iron with a low carbon content are very easy to magnetize and are HIGHLY PERMEABLE. These magnetic materials readily conduct the lines of force or flux.

Magnetic materials that are hard to magnetize have LOW PERMEABILITY. Hard steel with a high carbon content is HARD to magnetize and has LOW PERMEABILITY.

A horseshoe magnet is made of very hard, high carbon content steel. Would you say that the horseshoe magnet is highly permeable?

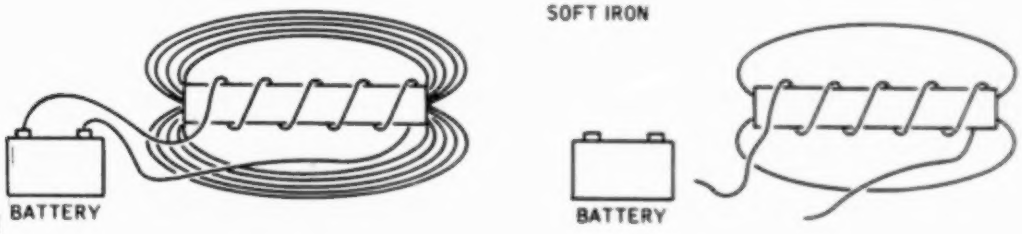
No . . . . Page 1-40

Yes . . . . Page 1-41

From page 1-39

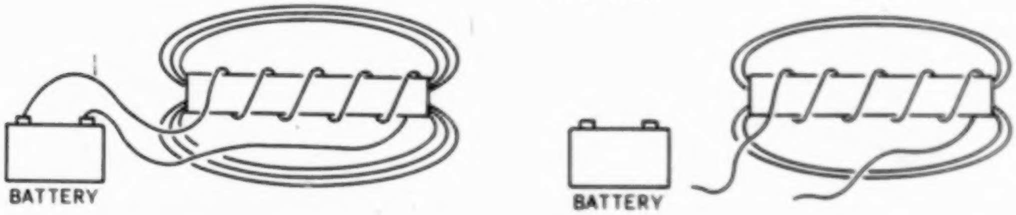
Right. Of course the horseshoe magnet is not highly permeable. Soft iron is easy to magnetize and is HIGHLY PERMEABLE. Very hard steel has LOW PERMEABILITY and is hard to magnetize.

SOFT IRON



Electric current is used to create a magnetic field in magnetic material. The magnetic field that remains in the metal after the magnetizing current is shut off is called RESIDUAL MAGNETISM.

HARD STEEL



Although hard steel has low permeability and is difficult to magnetize, it will hold some of the magnetism after the magnetizing current is shut off. That is how a permanent magnet like the horseshoe magnet is made. The magnetism retained in the horseshoe magnet is called RESIDUAL MAGNETISM.

Which of the following types of materials do you think would retain the most residual magnetism?

Magnetic material with high permeability . . . . Page 1-42

Magnetic material with low permeability . . . . Page 1-43

You think the horseshoe magnet is highly permeable. It is just the opposite. The word permeable may be causing the misunderstanding.

PERMEABILITY comes from the word "permeate" meaning to spread through. Permeability as we are using it, means the ease with which the lines of force are able to spread through the metal.

High permeability means that it is easy for the lines of force to spread through the metal.

Low permeability means that it is hard for the lines of force to spread through the material.

REMEMBER --

HIGH PERMEABILITY--EASY TO MAGNETIZE.

LOW PERMEABILITY--DIFFICULT TO MAGNETIZE.

High carbon content steel is difficult to magnetize. Therefore, it has low permeability. The horseshoe magnet has LOW PERMEABILITY.

Turn to page 1-40.

From page 1-40

You feel that magnetic material with high permeability would retain the most RESIDUAL MAGNETISM. That is incorrect and here is why.

Soft iron is easy to magnetize and is highly permeable. While these magnetic materials are highly permeable, they retain or hold very little of the residual magnetism after the magnetizing current is shut off.

REMEMBER--High permeability means low RESIDUAL MAGNETISM.

Turn to page 1-43.

From page 1-40

Correct. Magnetic material with low permeability would retain the most residual magnetism. Residual magnetism is the magnetic field retained in the material after the magnetizing current is shut off.

Residual magnetism is always less than the magnetic field which is present when the magnetizing current is on.

The amount of residual magnetism retained by a magnetic part will vary with the material. For example, tool steel with a high carbon content will retain a stronger residual magnetic field than will steel with a low carbon content.

Soft magnetic material, such as iron and iron with a low carbon content, are very easily magnetized and are highly permeable. Unlike hard steel, soft iron will retain only a small amount of magnetism after the magnetizing current is removed. Soft iron retains very little residual magnetism.

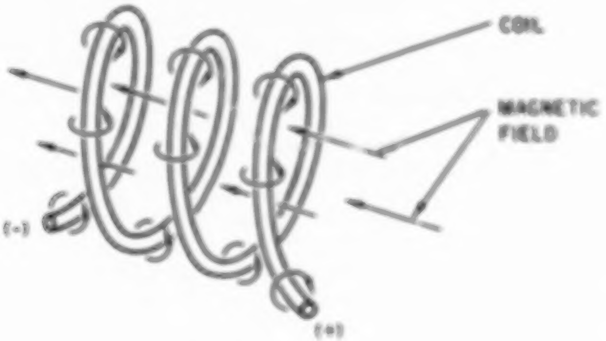
Magnetic material with low permeability would have which of the following?

Strong residual magnetism . . . . Page 1-44

Weak residual magnetism . . . . Page 1-45

Very good. Magnetic materials with low permeability would have strong residual magnetism.

The permeability of a given material can be determined. As you will recall, electric current is used to create a magnetic field. A piece of copper wire wound into a coil will create a magnetic field when electric current is passed through the wire.



By varying the electric current strength in the wire, the number of lines of force or flux within the coil will vary. The total number of lines of flux is called magnetic flux. If we increase the current in the wire, what do you think would happen to the magnetic flux?

Magnetic flux would increase	Page 1-46
Magnetic flux would decrease	Page 1-47

From page 1-43

You feel that material of low permeability would have weak residual magnetism. You have it backwards.

REMEMBER:

> HIGH PERMEABILITY means easily magnetized--WEAK residual magnetism.
>
> LOW PERMEABILITY means difficult to magnetize--STRONG residual magnetism.

Turn to page 1-44.

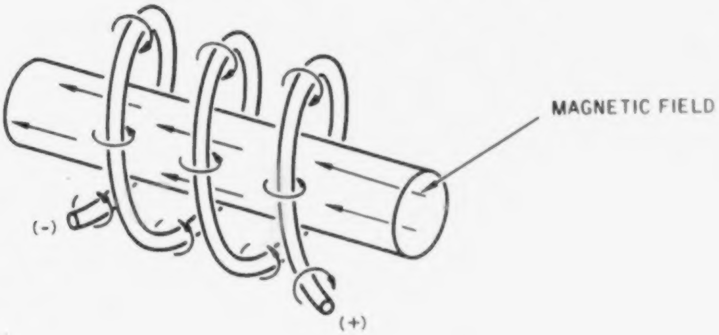
From page 1-44

Right. By increasing the magnetizing force (electric current strength), we increase the number of lines of flux. Flux density would increase. Thus we increase the strength of the magnetic field.

FLUX DENSITY IS DEFINED AS:

THE NUMBER OF LINES OF FORCE PER UNIT AREA.

By placing a piece of magnetic material inside the coil, a magnetic field is induced into the material.



The permeability of this particular material can be determined by increasing the magnetizing force (electric current strength) until the material reaches its saturation point. Since different materials have a different saturation point, we can determine the permeability of each type of material. Each will hold only a certain number of lines of flux. Therefore, we can say that each type of material has a point of:

Minimum flux density . . . . Page 1-48

Maximum flux density . . . . Page 1-49

From page 1-44

You selected—Magnetic flux would decrease. Actually, it is just the opposite.

Without electric current flowing in the copper wire, there is no magnetic field. When the electric current is turned on at a low current setting, the magnetic field is established. The total number of lines of force or flux running down the center of the coil is called the magnetic flux. By increasing the electric current flowing in the wire, more lines of flux are formed. So you see, when we increase the amount of current in the wire of the coil, the magnetic flux will increase.

Turn to page 1-46.

From page 1-46

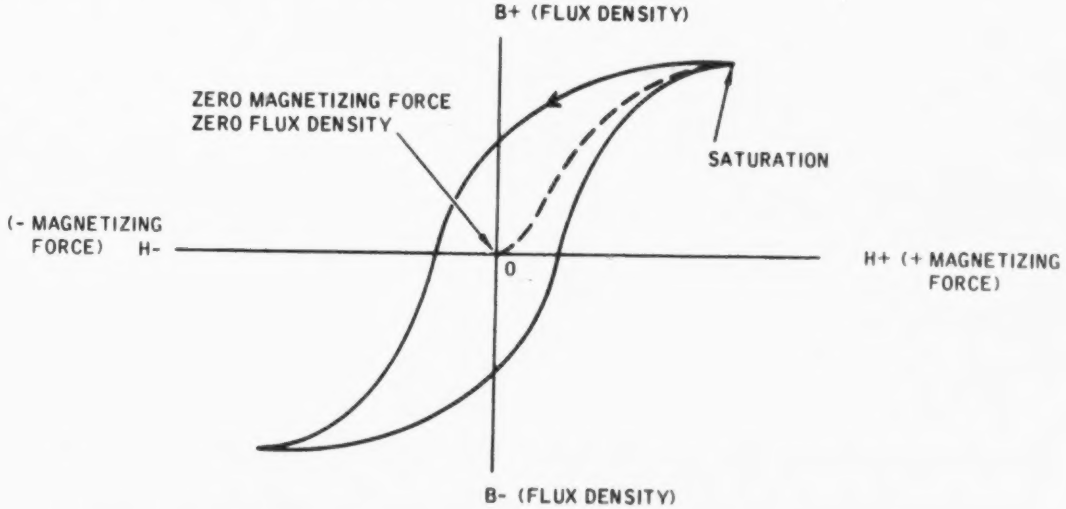
Well, each type of material has a minimum flux density all right--ZERO lines of flux. But we were talking about the saturation point of different materials. The point where each type of material will no longer hold more lines of flux. When the electric current is shut off, only a certain amount of magnetism will remain in the part no matter how much electric current was used. This is called the materials saturation point--Its MAXIMUM FLUX DENSITY.

Turn to page 1-49.

From page 1-46

That's right. Each type of material has a point of maximum flux density. At this point, an increase in the magnetizing force will have no effect on flux density — the material is said to be "saturated."

If we place a piece of steel in the coil, through which alternating current is flowing, we can plot the relation between magnetizing current, H, and flux density, B. The result is a hysteresis loop like this.

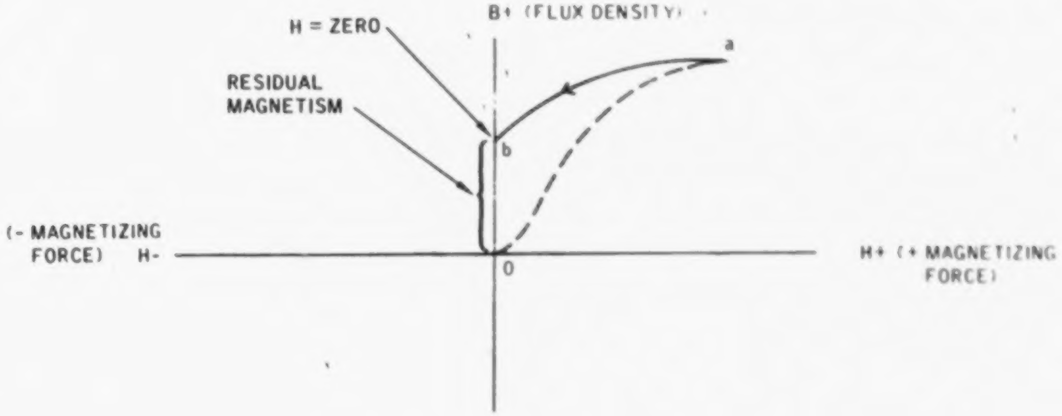

B+ (FLUX DENSITY)
ZERO MAGNETIZING FORCE
ZERO FLUX DENSITY
SATURATION
(- MAGNETIZING FORCE) H-
0
H+ (+ MAGNETIZING FORCE)
B- (FLUX DENSITY)

We start at point 0 (zero magnetizing force) with an unmagnetized piece of steel and increase the magnetizing force in small amounts. At each increase of the force H, we have an increase in flux density B until the saturation point is reached. This dashed line (which starts at zero) is called the virgin curve of this piece of steel. It shows the point of saturation for the piece of steel. In other words, it shows:

Maximum flux density for the steel . . . . Page 1-50
Maximum magnetizing force used . . . . Page 1-51

Very good. The dashed line shows the maximum flux density for the steel. It shows the maximum lines of flux which can be contained in that particular piece of steel.

The hysteresis loop will tell us a great many things about our piece of steel so let us break the loop down and start from scratch.

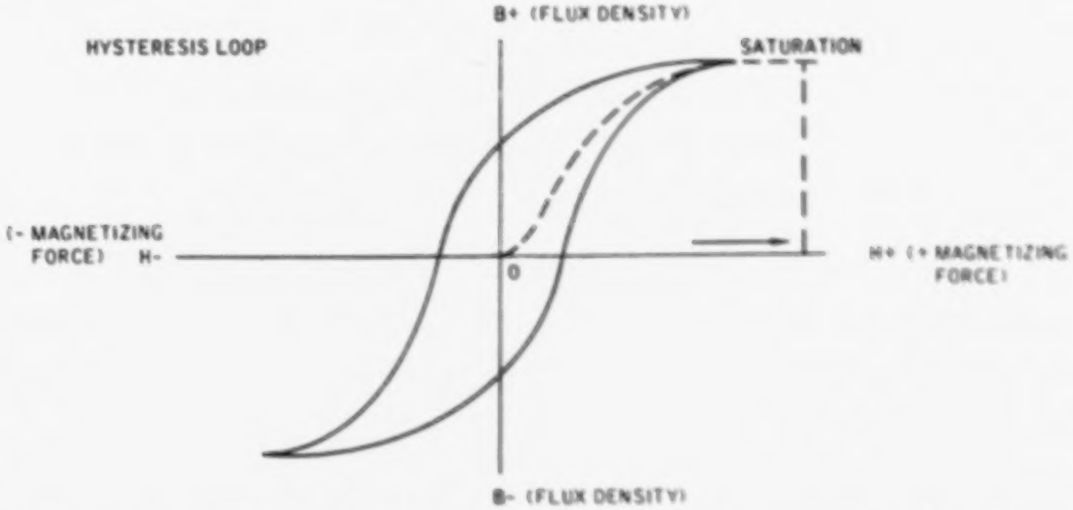


Along the dashed line, the flux density increases as magnetizing force is increased until it reaches a point beyond which any increase in the magnetizing force does not increase the flux. At this point (point a) the steel is saturated. As the magnetizing force is reduced to zero (point b), the flux density drops off slowly until the magnetizing force (current) is zero. The distance between points o and b represents the residual magnetism. The ability of the steel to retain a certain amount of residual magnetism is called RETENTIVITY. Which of the following do you think would have the greatest retentivity.

Material of high permeability . . . . Page 1-52

Material of low permeability . . . . Page 1-53

You selected--Maximum magnetizing force used. The chart didn't show that and here is the reason why.


B+ (FLUX DENSITY)
HYSTERESIS LOOP
SATURATION
(- MAGNETIZING FORCE) H-
0
H+ (+ MAGNETIZING FORCE)
B- (FLUX DENSITY)

Actually, a considerable amount of excess electric current (magnetizing force) may have been used. Notice that the arrow points to the maximum magnetizing force which could have been used in this case. It is considerably greater than that needed to obtain the maximum flux density. So you see, the chart shows the maximum flux density for the steel. The magnetizing force could have been any high value above that needed to saturate the steel.

Turn to page 1-50.

From page 1-50

You think material of high permeability would have the greatest retentivity. Don't let that word "retentivity" throw you. Let's define it right here.

RETENTIVITY IS DEFINED AS:

> THE ABILITY OF A MATERIAL TO RETAIN A PORTION OF THE MAGNETIC FIELD SET UP IN IT AFTER THE MAGNETIZING FORCE HAS BEEN REMOVED.

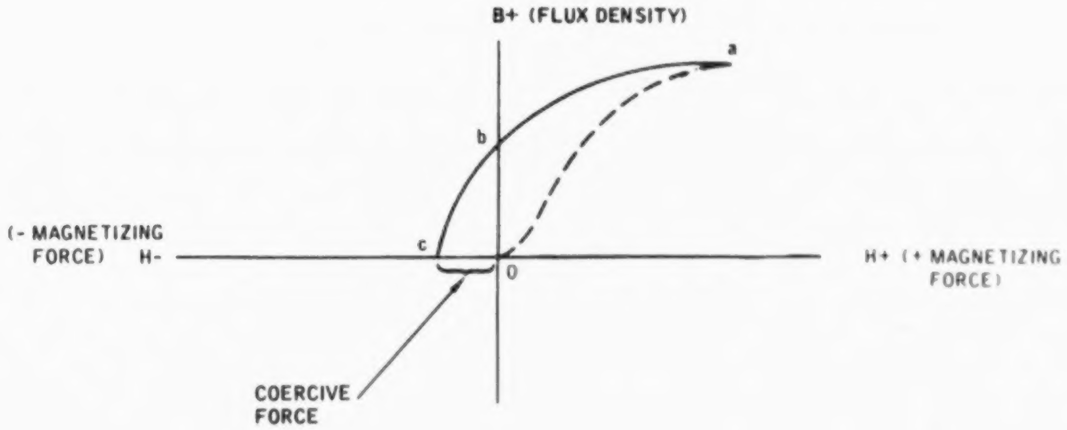
Now, material of high permeability retains only a small amount of residual magnetism after the magnetizing force is removed. On the other hand, it is very easily magnetized. Soft iron and iron with a low carbon content are examples of materials having high permeability.

Materials of low permeability retain a strong residual magnetism after the magnetizing force is removed. These materials are hard to magnetize. Very hard steel, like that of a horseshoe magnet, has high retentivity--it retains a strong residual magnetic field.

Turn to page 1-53.

Absolutely. Material of low permeability (hard steel) would have the greatest retentivity. It would retain the strongest residual magnetism--like a magnet.

If the magnetizing force is now reversed, as is the case with alternating current, and gradually increased in the reversed direction, the flux density is reduced to zero at point c.



With flux density reduced to zero at point c, we can determine the coercive force for the piece of steel.

COERCIVE FORCE IS DEFINED AS:

> THE REVERSE MAGNETIZING FORCE REQUIRED TO REMOVE THE RESIDUAL MAGNETISM FROM THE MATERIAL.

Which of the following would require the strongest coercive force to remove residual magnetism?

Iron . . . . Page 1-54

Hard steel . . . . Page 1-55

You think iron would require the strongest coercive force to remove the residual magnetism. Don't forget now, iron is soft in comparison to steel. Iron, particularly very soft iron, retains or holds only a small amount of residual magnetism after the magnetizing force is removed. Here is the definition again:

COERCIVE FORCE IS DEFINED AS:

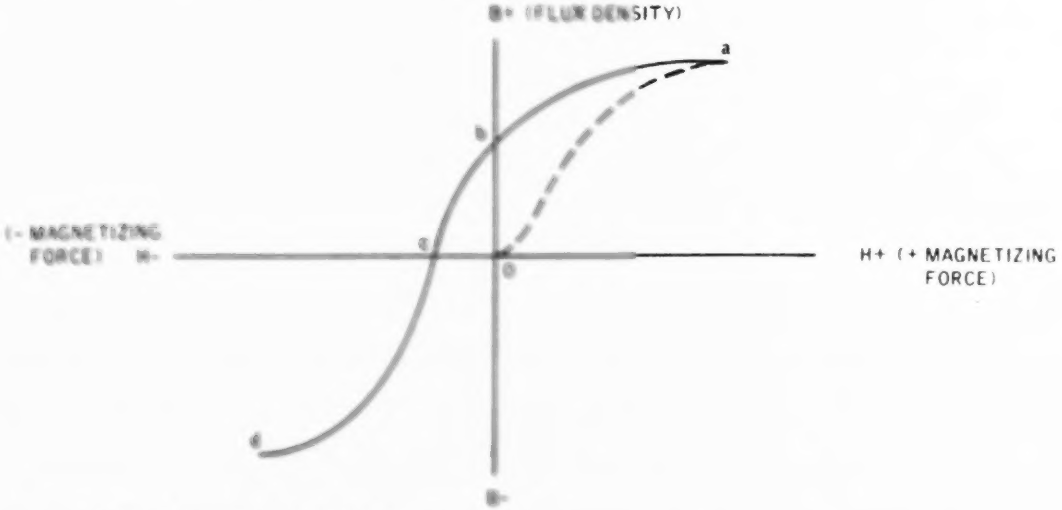
> THE REVERSE MAGNETIZING FORCE REQUIRED TO REMOVE THE RESIDUAL MAGNETISM FROM THE MATERIAL.

Since hard steel has high retentivity--retains a strong residual magnetic field--don't you agree that it would require the strongest coercive force to remove the residual magnetism?

Turn to page 1-55.

Yep, that's right. Hard steel would require the strongest coercive force. In other words, hard steel would require the strongest reverse magnetizing force to remove the residual magnetism. Hard steel also has the greatest retentivity--retains the strongest residual magnetic field.

As the reverse magnetizing force is increased beyond point c, flux density increases to the saturation point in the reverse direction--point d.



We have defined coercive force as:

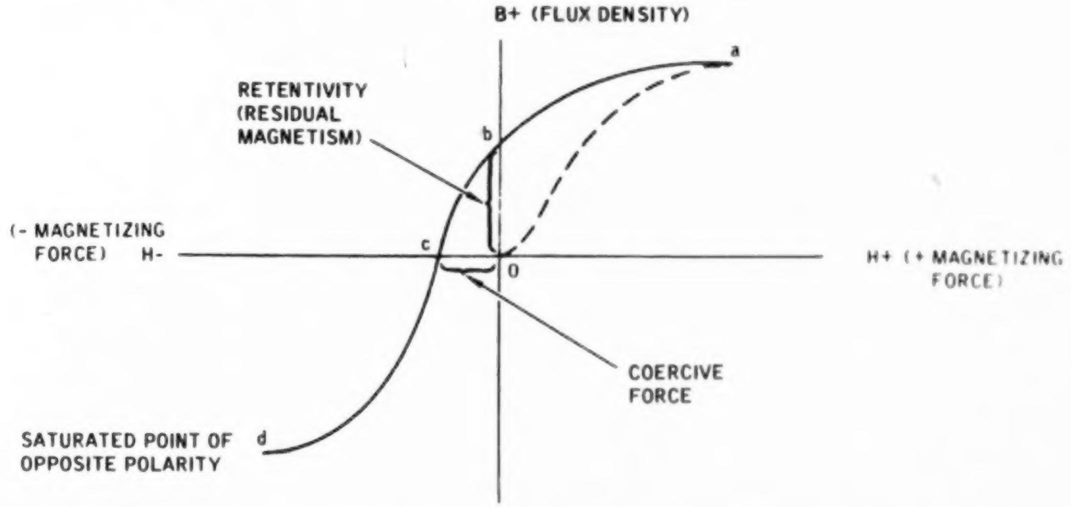
> THE REVERSE MAGNETIZING FORCE REQUIRED TO REMOVE THE RESIDUAL MAGNETISM FROM THE MATERIAL.

Between which of the following points on the hysteresis loop is the coercive force shown?

Between points 0 (Zero) and b . . . . Page 1-56

Between points 0 (Zero) and c . . . . Page 1-57

You think the coercive force is shown between points 0 (zero) and b. Let's take another look at the hysteresis loop and see if you still feel that way.


B+ (FLUX DENSITY)
a
RETENTIVITY (RESIDUAL MAGNETISM)
b
(- MAGNETIZING FORCE) H-
c
0
H+ (+ MAGNETIZING FORCE)
COERCIVE FORCE
SATURATED POINT OF OPPOSITE POLARITY
d

Along the dashed line, flux density increases until the steel is saturated (point a). When the magnetizing force is reduced to zero (point b) we can measure the residual magnetism as shown. If the magnetizing force is now reversed and gradually increased in the reversed direction, flux density is reduced to zero at point c. It is between points c and 0 that we measure the coercive force required to eliminate or remove the residual magnetism from the material.

Remember, coercive force is defined as:

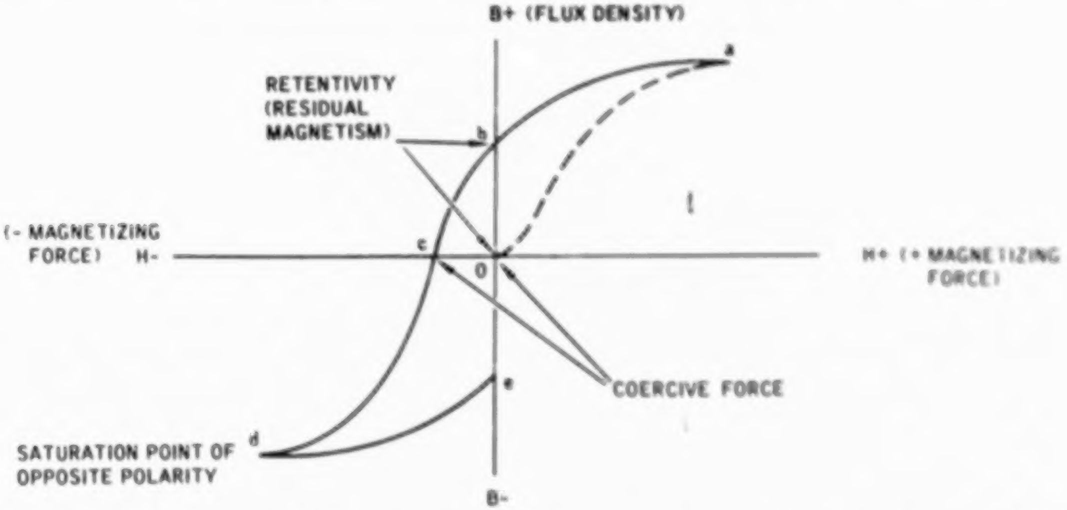
> THE REVERSE MAGNETIZING FORCE REQUIRED TO REMOVE THE RESIDUAL MAGNETISM FROM THE MATERIAL.

So you see, the coercive force is shown between points 0 (zero) and c.

Turn to page 1-57.

From page 1-55

Good for you. Coercive force is shown between points 0 (Zero) and c. The other area, points 0 and b represented the residual magnetism or retentivity of the material.


B+ (FLUX DENSITY)
a
RETENTIVITY (RESIDUAL MAGNETISM)
b
(- MAGNETIZING FORCE) H-
c
0
H+ (+ MAGNETIZING FORCE)
COERCIVE FORCE
e
d
SATURATION POINT OF OPPOSITE POLARITY
B-

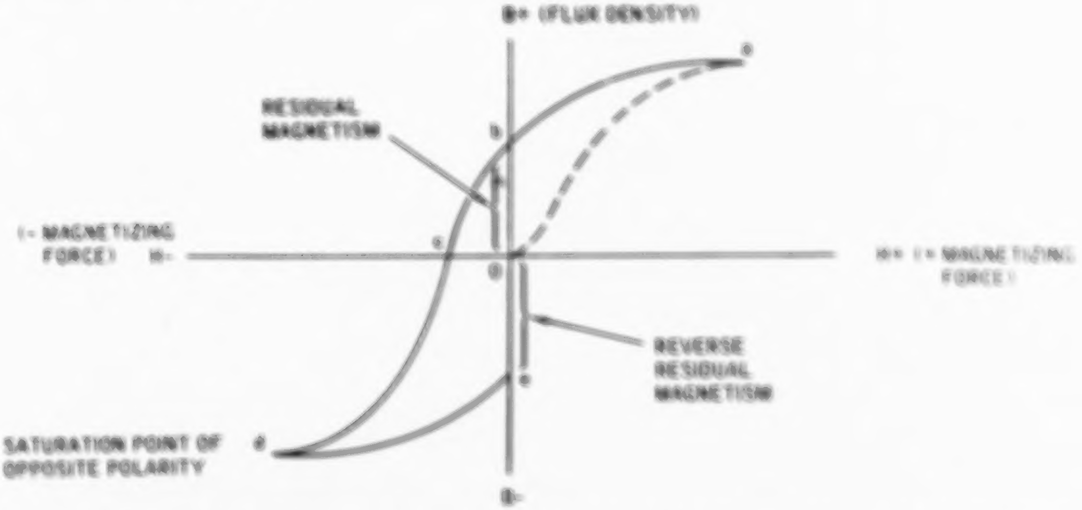
Point d on the hysteresis loop is the point of maximum saturation in the reverse direction. In other words, the steel has been magnetized to its maximum flux density in the reverse direction. If we again reduce the magnetizing force to zero (point e), which of the following do you think will exist?

Residual magnetism . . . . Page 1-58

Reverse residual magnetism . . . . Page 1-59

From page 1-57

You selected--Residual magnetism. It isn't the answer we were after, but you are right although a little incomplete. If we reduce the magnetizing force to zero (point c) in the reversed direction there will be residual magnetism--except that it will be reverse residual magnetism.

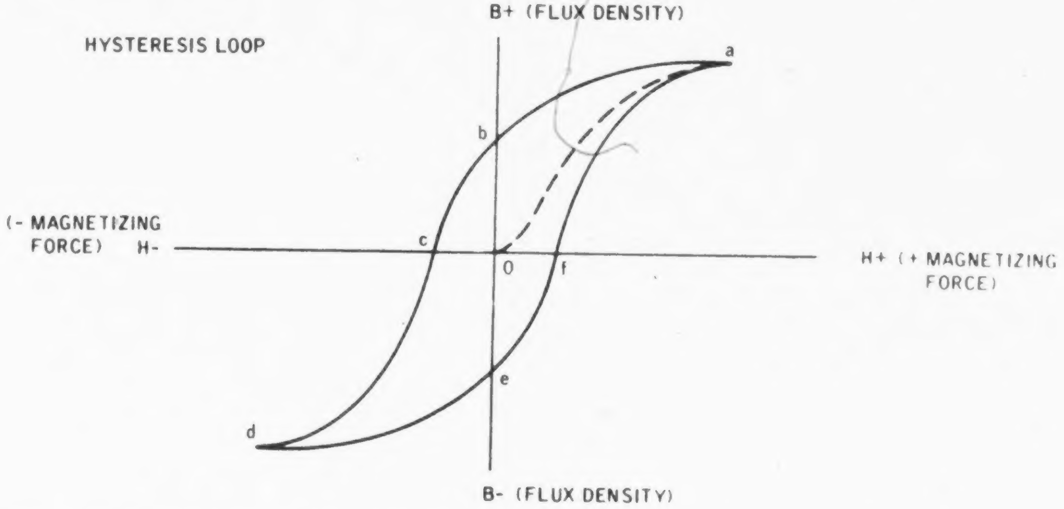

B+ (FLUX DENSITY)
a
RESIDUAL MAGNETISM
b
(- MAGNETIZING FORCE) H-
c
0
H+ (+ MAGNETIZING FORCE)
REVERSE RESIDUAL MAGNETISM
e
SATURATION POINT OF OPPOSITE POLARITY
d
B-

Here you can see the two areas representing residual magnetism. The re-reduction of the magnetizing force to zero at point e results in reverse residual magnetism.

Turn to page 1-59.

Of course. If we again reduce the magnetizing force to zero (point e) in the reverse direction, we would have reverse residual magnetism. Point e also shows the retentivity--the ability of the material to retain residual magnetism.

By increasing the magnetizing force in the original direction we complete the hysteresis loop. Notice, however, that the dashed line is no longer followed. It was the "virgin curve," or first curve.


HYSTERESIS LOOP
B+ (FLUX DENSITY)
a
b
(- MAGNETIZING FORCE) H-
c
0
f
H+ (+ MAGNETIZING FORCE)
e
d
B- (FLUX DENSITY)

Having established a residual magnetic field in the reverse direction, it will be necessary to remove it. The force required to remove this residual field is shown between points 0 and f. What is the name of the REVERSE MAGNETIZING FORCE REQUIRED TO REMOVE THE RESIDUAL MAGNETISM FROM THE MATERIAL?

Retentivity	Page 1-60
Coercive force	Page 1-61
Magnetizing force	Page 1-62

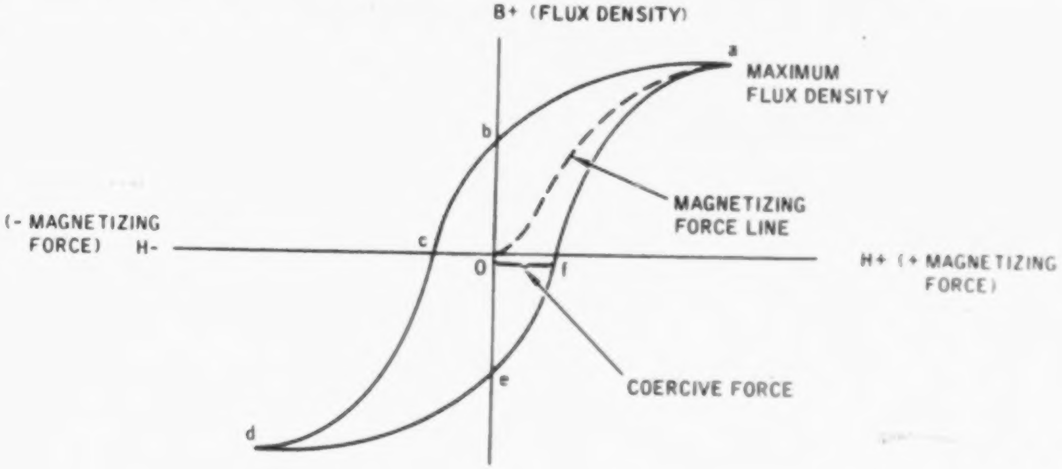
You selected--Retentivity. No, that isn't the name of the reverse magnetizing force required to remove the residual magnetism from the material.

RETENTIVITY is defined as:

> THE ABILITY OF A MATERIAL TO RETAIN A PORTION OF THE MAGNETIC FIELD SET UP IN IT AFTER THE MAGNETIZING FORCE HAS BEEN REMOVED.

Return to page 1-59 and try again.

Yes sir. Coercive force is the correct answer. That is the name of the reverse magnetizing force required to remove the residual magnetism from the material. In this case, the coercive force is shown between points 0 and f.



The hysteresis loop gets its name from the lag between the magnetizing force and the increase of flux density throughout the cycle. This lag is called HYSTERESIS. The lag is shown between points 0 and f.

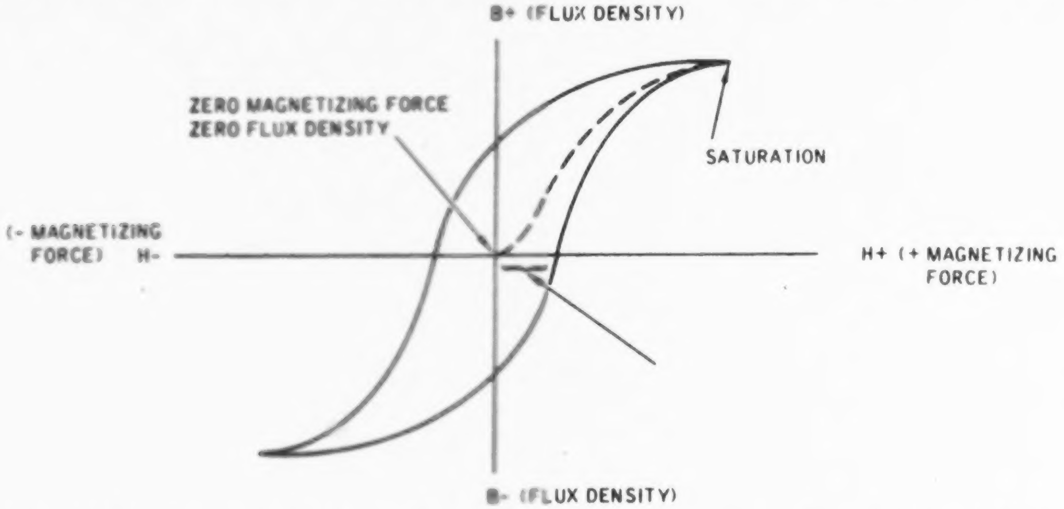
A material that is hard to magnetize is said to have HIGH RELUCTANCE.
RELUCTANCE IS DEFINED AS:

THE RESISTANCE OF A MATERIAL TO A MAGNETIZING FORCE

A very hard piece of steel is hard to magnetize but would retain a strong residual magnetic field. If a hysteresis loop was plotted for the very hard steel, what would happen to the distance between points 0 and f. In other words, would the coercive force have to be stronger or weaker?

Stronger . . . . Page 1-63
Weaker . . . . Page 1-64

You think MAGNETIZING FORCE is the name of the reverse magnetizing force required to remove the residual magnetism from the material. No, what we are after is the name of a specific portion of the magnetizing force. Here is the hysteresis loop again.

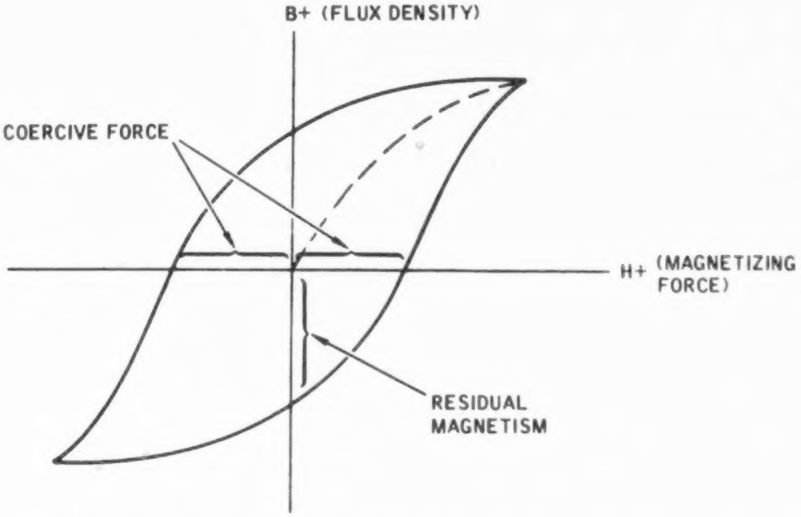

B+ (FLUX DENSITY)
ZERO MAGNETIZING FORCE
ZERO FLUX DENSITY
SATURATION
(- MAGNETIZING FORCE) H-
H+ (+ MAGNETIZING FORCE)
B- (FLUX DENSITY)

The arrow is pointing at the specific portion of the magnetizing force we are talking about. This area shows the REVERSE MAGNETIZING FORCE REQUIRED TO REMOVE THE RESIDUAL MAGNETISM FROM THE MATERIAL.

Return to page 1-59 and select the correct name for this area.

From page 1-61

Stronger is the right answer. Because a very hard piece of steel would retain a strong residual magnetic field, the reverse magnetizing force required to remove the residual magnetism would have to be stronger. Here is a typical hysteresis loop for a very hard piece of steel.



Here you can see that the coercive force would have to be stronger because the residual magnetic field in the part would be stronger. A wide hysteresis loop indicates a material that is difficult to magnetize--high reluctance. In short, this loop shows that hard steel would have the following qualities:

1. LOW PERMEABILITY---hard to magnetize.
2. HIGH RETENTIVITY---retains a strong residual mangentic field.
3. HIGH COERCIVE FORCE---requires a high reverse magnetizing force to remove the residual magnetism.
4. HIGH RELUCTANCE---high resistance to magnetizing force.
5. HIGH RESIDUAL MAGNETISM---retains a strong residual magnetic field.

Turn to page 1-65.

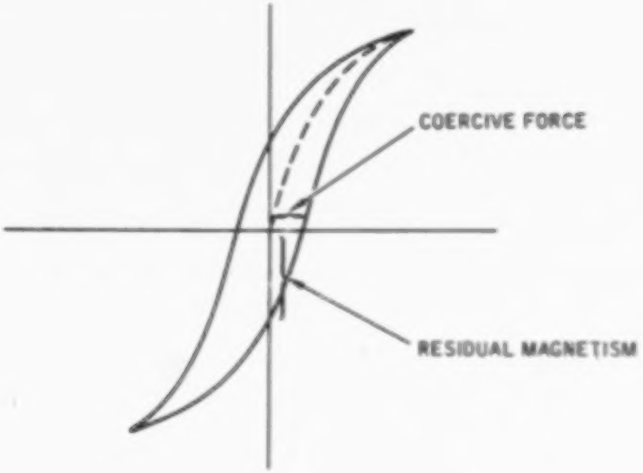
You are guessing. You feel that the coercive force would be weaker for a very hard piece of steel. Let's review the characteristics of hard steel.

Hard steel has low permeability---it is hard to magnetize.
Hard steel has high retentivity---it retains a strong residual field.
Hard steel has high reluctance---it has high resistance to a magnetizing force.

In other words, with high reluctance, the very hard steel would require a stronger coercive force.

Turn to page 1-63.

A thin loop indicates a material of low retentivity.



This hysteresis loop shows the qualities of a soft material like iron with a low carbon content. The coercive force is low because the material retains only a weak residual magnetic field. In short, this loop shows that soft iron would have the following qualities:

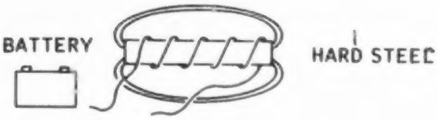
1. HIGH PERMEABILITY---easy to magnetize.
2. LOW RETENTIVITY---retains a weak residual magnetic field.
3. LOW COERCIVE FORCE---requires a low reverse magnetizing force to remove the residual magnetism.
4. LOW RELUCTANCE---low resistance to magnetizing force.
5. LOW RESIDUAL MAGNETISM---retains a weak residual magnetic field.

Turn to page 1-66.

From page 1-65

1. The next few pages are different from the ones which you have been reading. There are _____ arrows on this entire page. (Write in the correct number of arrows.) Do not read the frames below. FOLLOW THE ARROW and turn to the TOP of the next page. There you will find the correct word for the blank line above.

15. high
weak



16. Hard steel is more difficult to magnetize, but when the current is shutoff, the steel retains most of its magnetism. Hard steel has _____ permeability but retains a _________ residual magnetic field.

30. low
strong

31. PERMEABILITY is defined as:
THE EASE WITH WHICH MATERIALS CAN BE ______________ .

45. coercive

46. The amount of coercive force required to remove the residual magnetism, is a measure of the RELUCTANCE of the material.
RELUCTANCE is defined as:
THE RESISTANCE OF A MATERIAL TO A _______________ FORCE.

This is the answer to the blank in Frame number 1.

1. four **Frame 2 is next**

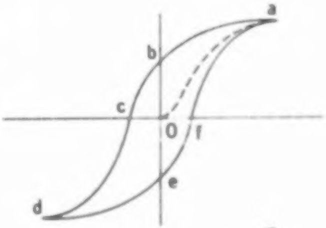
2. These pages will provide a review of the material you have covered to this point. There will be one or more blanks in each f__________.

16. low
strong

17. Soft ferromagnetic material is easy to magnetize but retains very little magnetism. Hard ferromagnetic material is hard to magnetize but retains most of the magnetism. The ease with which ferromagnetic material can be magnetized is a measure of its ______________.

31. MAGNETIZED

32. The permeability of a specific material can be determined by its ______________ loop.



46. magnetizing

47. A very hard piece of steel is hard to magnetize and is said to have HIGH RELUCTANCE and retains a strong residual magnetic field. Removal of the residual field would require a (strong) (weak) ______________ coercive force.

2. frame

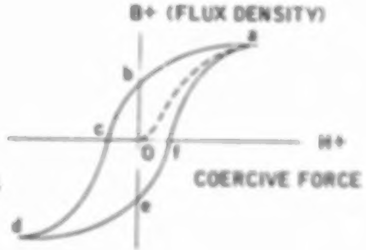
3. By following the arrows or instructions you will be directed to the page which follows in sequence. Each section presents information and requires the filling in of __________________.

17. permeability

18. THE EASE WITH WHICH MATERIALS CAN BE MAGNETIZED IS THE DEFINITION OF ______________. Soft iron is very easy to magnetize and has high ________________.

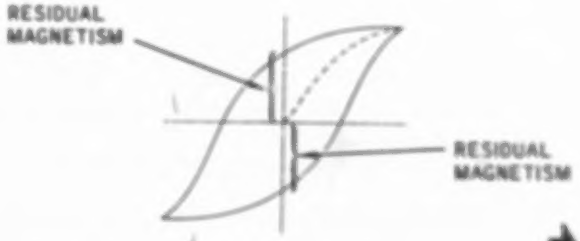
32. hysteresis

33. The ratio of flux density (B+) to magnetizing force (H+) = the per________________ of the material.


B+ (FLUX DENSITY)
a
b
c
O
f
H+
COERCIVE FORCE
d
e

47. strong

48. A wide hysteresis loop indicates a material that is difficult to magnetize. The material has high re________________.


RESIDUAL MAGNETISM
RESIDUAL MAGNETISM

3. blanks

4. By definition, ferrous means "of, or pertaining to ir________."

18. permeability,
permeability

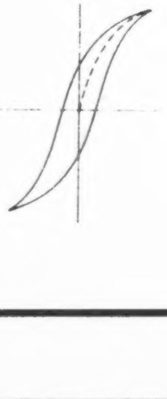
19. Hard steel with a high carbon content is hard to magnetize and has ________ permeability.

33. permeability

34. The total number of lines of force per unit area is called _____ ________.

48. reluctance

49. A thin hysteresis loop indicates
a material that is easy to magnetize.
The material has _____ reluctance.



4. iron

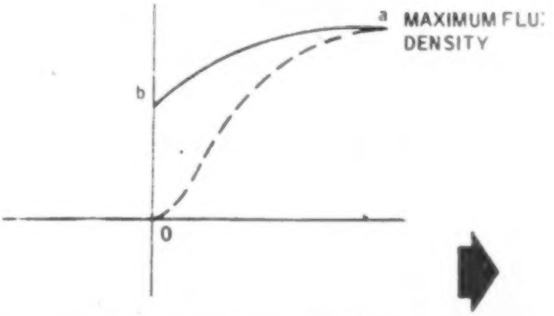
5. A nail is made of iron so it is made of f__________ material.

19. low

20. Soft iron is __________ permeable.

34. flux density

35. Maximum saturation for the material is shown at point "a." In other words, point "a" shows the maximum number of lines of force the material will hold. It is the point of maximum __________.



49. low

50. **THE EASE WITH WHICH MATERIALS CAN BE MAGNETIZED** is the definition of __________.

5. ferrous

6. A nail is made of iron which is ferrous metal. Since the nail is attracted to a magnet it is called ferro______________ material.

20. highly

21. Hard steel has__________permeability.

35. flux density

36. FLUX DENSITY is defined as:
THE NUMBER OF LINES OF FORCE PER UNIT A__________.

50. PERMEABILITY

51. THE ABILITY OF MATERIAL TO RETAIN A CERTAIN AMOUNT OF RESIDUAL MAGNETISM is the definition of______________.

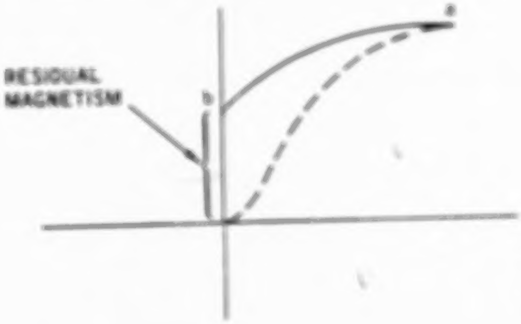
6. ferromagnetic

7. A piece of copper wire will not be attracted to a magnet and it is called nonm____________ material.

21. low

22. Electric current is the magnetizing force used to create a magnetic field in ferromagnetic material. The magnetic field that remains in the metal after the magnetizing force is removed, is called re________________ magnetism.

36. AREA



37. Point "a" on the hysteresis loop shows the maximum flux density for the steel. In other words, the steel is sat____________.

51. RETENTIVITY

52. THE MAGNETIC FIELD WHICH REMAINS IN A MATERIAL AFTER THE MAGNETIZING FORCE IS REMOVED is the definition of ________ ____________.

7. nonmagnetic

8. All ferromagnetic materials are attracted to a ______________ .

22. residual

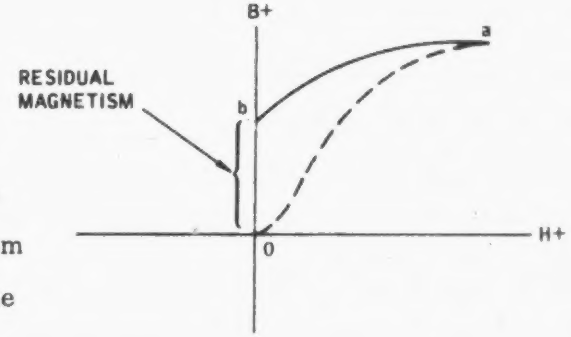
23. RESIDUAL MAGNETISM is defined as:

THE MAGNETIC FIELD WHICH REMAINS IN A MATERIAL AFTER THE MAGNETIZING FORCE (current) IS REMOVED.

Residual magnetism is always less than the magnetic field which is present when the magnetizing ________________ is on.

37. saturated

38. If the magnetizing force is reduced to zero (point b), we can measure the residual magnetism or re__________________ of the material.

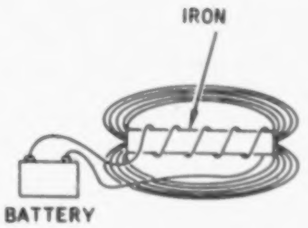


52. RESIDUAL MAGNETISM

53. THE REVERSE MAGNETIZING FORCE REQUIRED TO REMOVE RESIDUAL MAGNETISM FROM THE MATERIAL is the definition ________ __________ .

8. magnet
(magnetic field)

9. Electric current is used to create a magnetic field in ______________ material.



23. FORCE (current)

24. Hard metal has low permeability and will retain a strong ________ magnetic field.

38. retentivity

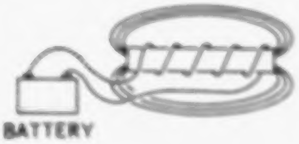
39. RETENTIVITY is defined as:
THE ABILITY OF A MATERIAL TO RETAIN A CERTAIN AMOUNT OF RESIDUAL MAGNETISM AFTER THE MAGNETIZING FORCE HAS BEEN REMOVED.
Hard steel retains a strong residual magnetic field and has high ____________________.

53. coercive force

54. THE RESISTANCE OF A MATERIAL TO A MAGNETIZING FORCE is the definition of __________________.

9. ferromagnetic

10. When the magnetizing force (current) is removed, the material retains some of the ______ ______ .

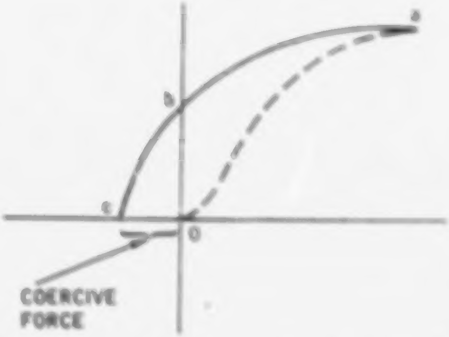


24. residual

25. Soft metal has high permeability and will retain a ______ residual field.

39. retentivity

40. If the magnetizing force is reversed and gradually increased in the reversed direction, flux density is reduced to zero at point c. The distance between points c and 0 (zero) measures the ______ ______ .



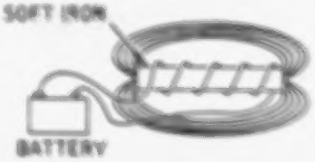
54. RELUCTANCE

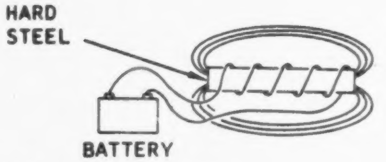
55. THE NUMBER OF LINES OF FORCE PER UNIT AREA is the definition of ______ ______ .

10. magnetic field

(magnetism)

11. Some materials are harder to magnetize than others.





This is caused by the permea__________ of the material.

25. weak

26. Soft metal will retain a weak residual field and is ________ permeable.

40. coercive force

41. COERCIVE FORCE is defined as:

THE REVERSE MAGNETIZING FORCE REQUIRED TO REMOVE THE __________

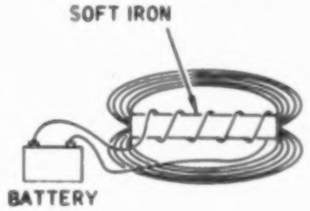
__________ ________________ FROM THE MATERIAL.

55. flux density

56. RELUCTANCE is defined as:

THE ________________ OF A MATERIAL TO A MAGNETIZING FORCE.

14. permeability

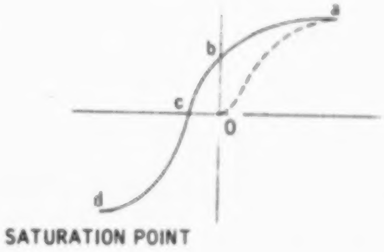


12. PERMEABILITY is defined as:
THE EASE WITH WHICH MATERIALS
CAN BE ________________ :
Soft iron is easy to magnetize so it has high ________________ .

25. highly

27. Hard metal will retain a strong residual field and has ______ permeability.

41. RESIDUAL MAGNETISM

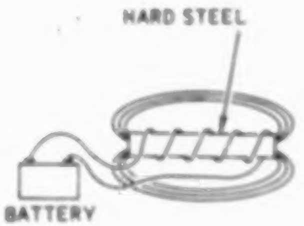


42. As the reverse magnetizing force is increased, flux density increases to the saturation point in the reverse direction (point d). This is a point of maximum ______ ____________ .

56. RESISTANCE

57. COERCIVE FORCE is defined as:
The ____________ MAGNETIZING FORCE REQUIRED TO REMOVE THE RESIDUAL MAGNETISM FROM THE MATERIAL.

12. magnetized
permeability



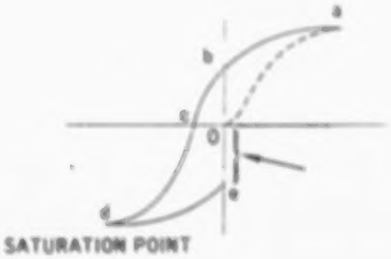
13. Hard steel is more difficult to magnetize so it has _____ permeability.

27. low

28. A horseshoe magnet is made of very hard material and will retain a
_______________ residual field.

42. flux density

43. If we again reduce the magnetizing force to zero (point e) in the reverse direction, we can measure the reverse
____________ ____________________ .



57. REVERSE

58. FLUX DENSITY is defined as:
THE NUMBER OF _______ OF _________ PER UNIT AREA.

13. low

14. **RESIDUAL MAGNETISM** is defined as:

THE MAGNETIC FIELD WHICH REMAINS IN A MATERIAL AFTER THE MAGNETIZING FORCE IS __________________ .

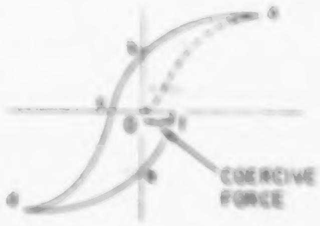
When the magnetizing force (electric current) is removed, soft iron retains a very weak _______________ magnetic field.

28. strong

29. The horseshoe magnet is made of very hard material and has _______________ permeability.

43. residual magnetism

44. By increasing the magnetizing force in the original direction to point f, we can measure the reverse magnetizing force required to remove the ____________ ______________ from the material.



58. LINES OF FORCE
(LINES OF FLUX)

59. End of review. Please turn to Chapter 2.

14. REMOVED
residual

15. Soft iron is easy to magnetize but does not retain very much magnetism. It has __________ permeability but retains a __________ residual magnetic field.

Return to page 1-66,
frame 16.

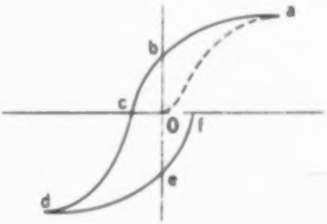
29. low

30. Hard ferromagnetic material has _____ permeability and retains a ____________ residual magnetic field.

Return to page 1-66,
frame 31.

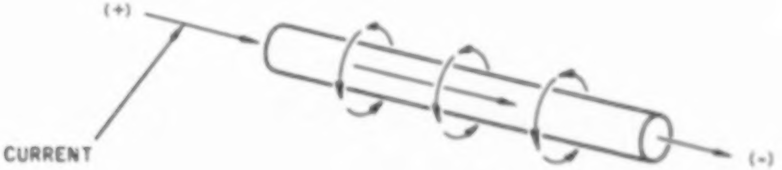
44. residual magnetism

45. The distance between points 0 (zero) and f, represents the magnetizing force required to remove the residual magnetism from the material. This force is called ______________ force.



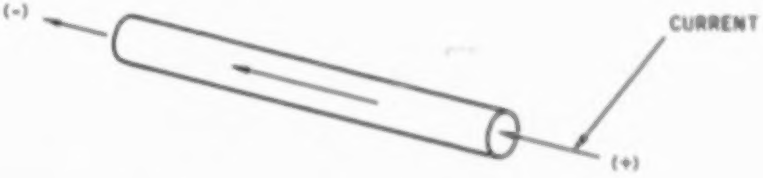
Return to page 1-66,
frame 46.

A magnetic field is produced by passing electric current through any material that will conduct electricity. The magnetic lines of force, or flux, are always at right angles to the direction of flow of the electric current. Consider a piece of copper wire through which electric current is flowing.



With electric current running along the wire, a magnetic field will be created around the wire. In this case, the lines of force, or flux, are traveling counterclockwise around the wire.

Here is a simple rule to assist in determining the direction of the lines of force. Imagine that you are grasping the wire with your right hand so that the thumb points in the direction of electric current flow: your fingers will now be pointing in the direction of flow of the lines of force. This method of determining the direction of lines of force is known as THE RIGHT-HAND RULE.

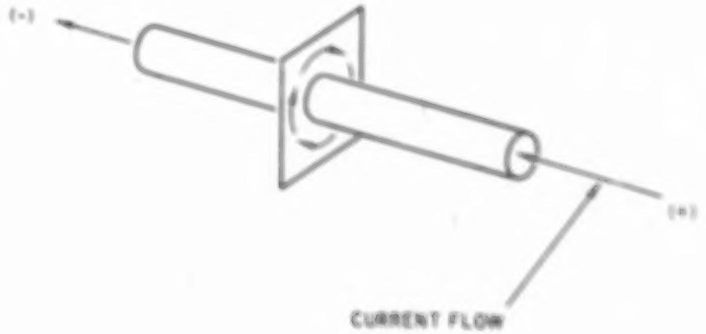


Using the right-hand rule, what is the direction of flow of the lines of force around this wire?

Counterclockwise ... . Page 2-2

Clockwise .... Page 2-3

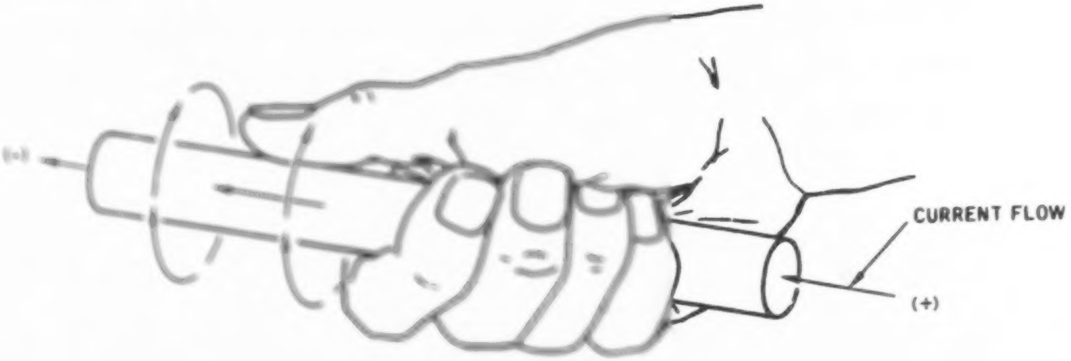
Counterclockwise is not correct. Perhaps we've confused you as to how we are looking at the wire. Let's look at it this way.



The wire has been passed through a piece of paper to give you a better idea of the direction of flow of the lines of force. They are flowing clockwise 90° to the direction of electric current flow. Return to page 2-1 and study the drawing again.

From page 2-1

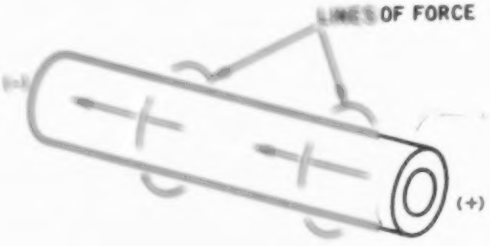
That's absolutely correct. The lines of force would be traveling around the wire clockwise like this.



By grasping the wire in the right hand with the thumb pointing in the direction of current flow, the fingers will point in the same direction as the lines of force.

For our purposes here, let us assume that electric current flows from the positive (+) terminal to the negative (-) terminal.

Now, let's take a look at an end view of the wire.



In this view, we can see the magnetic lines of force, or flux, around the wire. The plus (+) sign in the center means that we are looking at the positive end of the wire. Using the right-hand rule, what would be the direction of flow of the lines of force, or flux, around the wire?

Clockwise .... Page 2-4

Counterclockwise .... Page 2-5

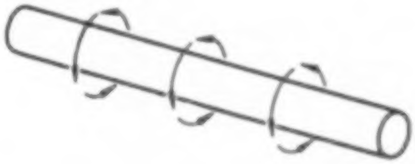
From page 2-3

That's the idea. The lines of force, or flux, would be turning clockwise around the wire. Here is the right-hand rule again.

> By grasping the wire with your right hand so that the thumb points in the direction of current flow, your fingers will point in the direction of the magnetic lines of force, or flux.

In addition, for the purpose of this book, we will always assume that current flows from the positive (+) terminal to the negative (-) terminal.

Now let's try a different twist with the right-hand rule.



Here is the wire with the magnetic lines of force, or flux, around it. By applying the right-hand rule you should be able to determine the direction of flow of the current within the wire.

Which of the following arrows is pointing in the direction of current flow through the wire?

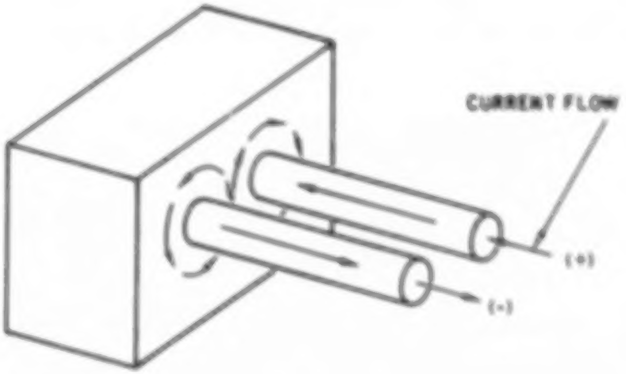
↘ .... Page 2-6

↖ .... Page 2-7

From page 2-3

Counterclockwise isn't the right answer. But using the (+) and the (-) signs to show the direction of current flow might be a little confusing, so let's clarify it.

This diagram may help.



Here you can see that electric current is flowing into the wire at the positive (+) end and the magnetic field around the wire is turning clockwise. When the electric current comes out of the wire on the left, which is the negative (-) end of the wire, the field is turning counterclockwise.

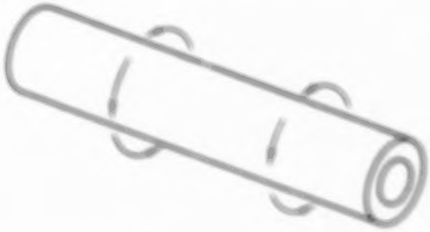
Now return to page 2-3 and apply the right-hand rule.

From page 2-4

Good for you. That's right. You seem to have the right-hand rule down pat. But let's carry it just one step further.

In addition to the right-hand rule, it is important to remember that current flows from the positive terminal (+) to the negative terminal (-).

Here is an end view of the wire with the lines of force flowing around it.

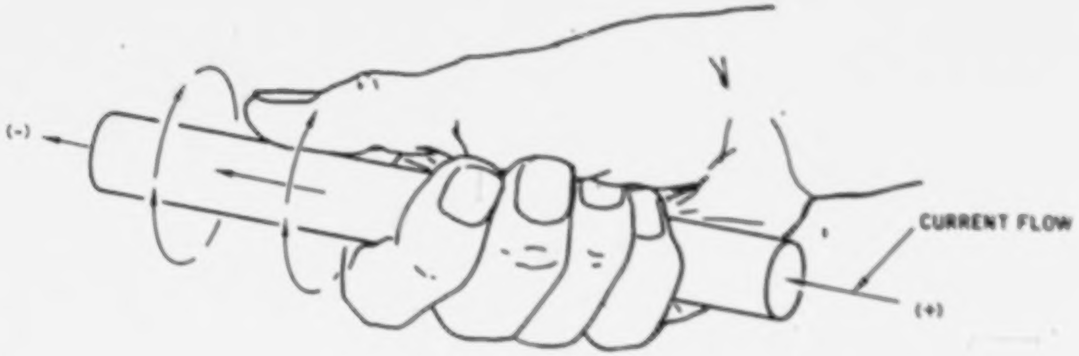


By applying the right-hand rule, you should be able to determine which end (positive or negative) of the wire we are looking at. See if you can.

The positive (+) end .... Page 2-8

The negative (-) end .... Page 2-9

Ooops. You picked the wrong direction. Let's briefly review the right-hand rule.



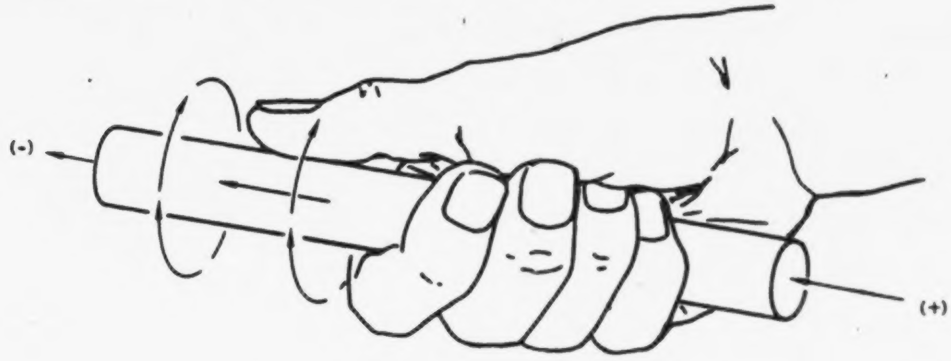
Note how the thumb is pointed in the direction of electric current flow. The fingers wrapped around the wire now point in the direction of the lines of force in the magnetic field,

Return to page 2-4 and try again.

It is easy to get mixed up on this one. Perhaps it will be easier for you to remember that when using the right-hand rule, the thumb always points towards the NEGATIVE TERMINAL (-).

Return to page 2-6 and study the problem again.

Right again. We were looking at the negative (-) end of the wire. Electric current always flows from the positive (+) to the negative (-).

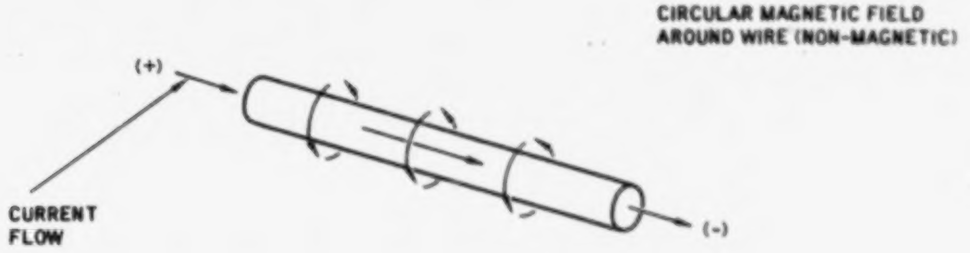


Here you can see the application of the right-hand rule in relation to the direction of current flow. The current is flowing from the positive (+) to the negative (-) terminals. The thumb of the right hand is pointing in the direction of current flow and the fingers are pointing in the direction of the magnetic lines of force or flux.

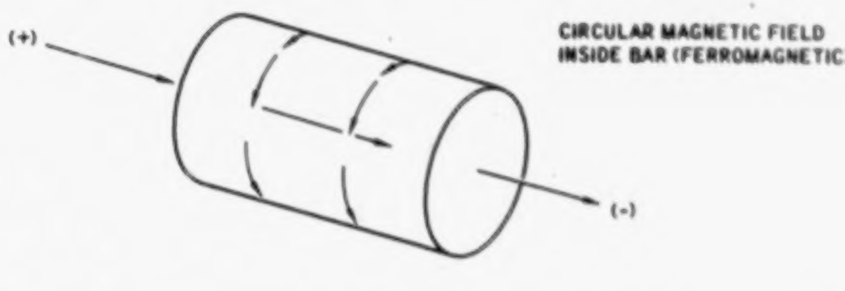
Turn to the next page.

CIRCULAR MAGNETIC FIELD

Circular magnetization uses the principles of establishing a magnetic field as we saw with the copper wire in previous pages. Since the copper wire is non-magnetic material, the lines of force will not stay in the copper wire. Instead, the magnetic field is established AROUND THE WIRE.


CIRCULAR MAGNETIC FIELD AROUND WIRE (NON-MAGNETIC)
(+)
CURRENT FLOW
(-)

When electric current flows through ferromagnetic material, the magnetic field is established WITHIN THE MATERIAL. The lines of force stay within the material because the material is permeable and readily conducts the lines of force. Consider what happens when electric current flows through this round steel bar.


(+)
CIRCULAR MAGNETIC FIELD INSIDE BAR (FERROMAGNETIC)
(-)

The lines of force, or flux, are contained within the steel bar. In both cases though, the lines of force, or flux, are at right angles, or 90° to the direction of electric current flow.

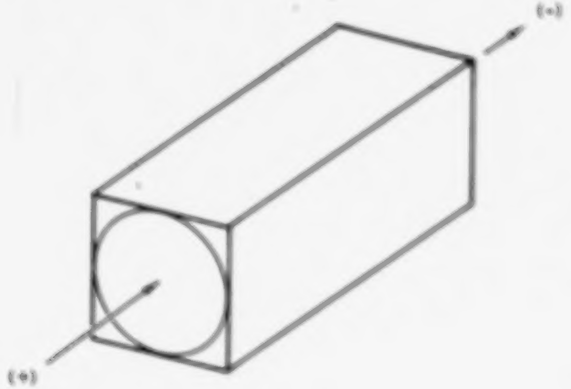
Do you think that the right-hand rule works the same for both the copper wire and the round steel bar?

Yes .... Page 2-11

No .... Page 2-12

"Yes" is right. The right-hand rule works exactly the same for the copper wire and the round steel bar. The only difference between the two is that the magnetic field forms around the copper wire, while the magnetic field stays within the round steel bar.

Here is another steel bar.



When electric current is passed through the steel bar in the illustration above, a circular magnetic field will be set up within the bar. What is the direction of the magnetic field?

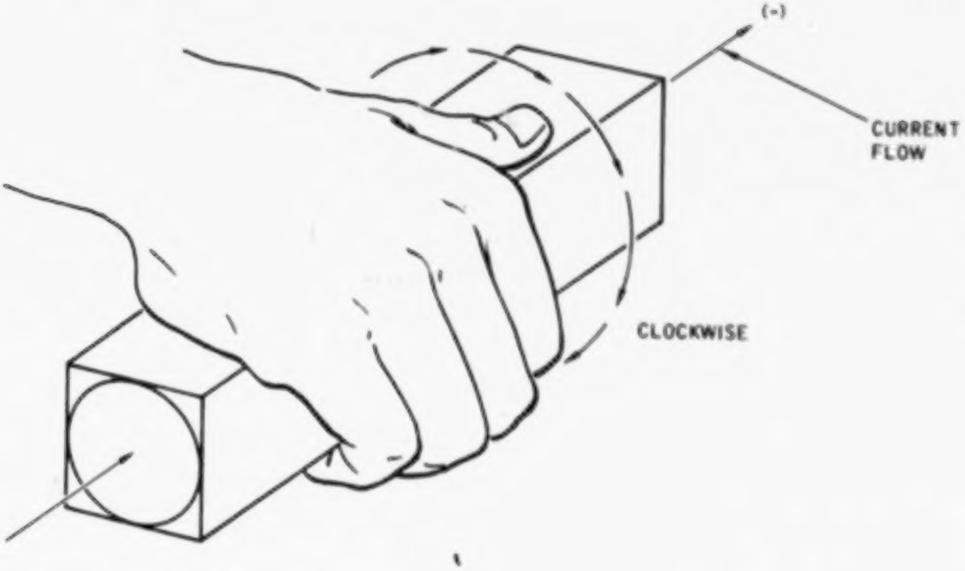
Counterclockwise .... Page 2-13
Clockwise .... Page 2-14

Sorry, the right-hand rule works the same for both the copper wire and the round steel bar.

With the thumb pointing in the direction of current flow, the fingers point in the direction of flow of the magnetic lines of force. Whether the magnetic field lies inside or outside of the material does not affect the application of the right-hand rule.

Return to page 2-10 and study the problem again.

Well, let's look at the bar from a different standpoint.

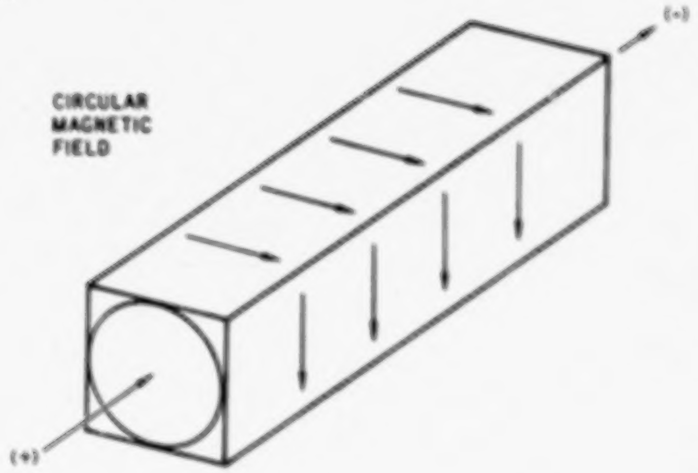


With the thumb pointing toward the negative terminal (direction of current), the fingers point in the direction of the magnetic field. In the case above, the fingers point in a clockwise direction.

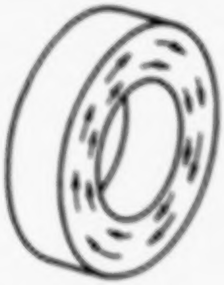
Note that the shape of the bar does not affect the direction of the circular magnetic field. So the magnetic field is flowing clockwise.

Turn to page 2-14.

Clockwise is right.



A CIRCULAR MAGNETIC FIELD will be set up with the lines of force running clockwise. The circular field will be contained entirely within the bar. In the steel bar, we have a situation like the one with the circle magnet discussed previously.



If we dust iron particles on this circular magnet, would they be attracted to any point on the magnet?

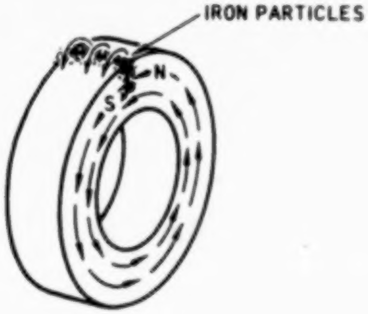
Yes .... Page 2-15
No .... Page 2-16

From page 2-14

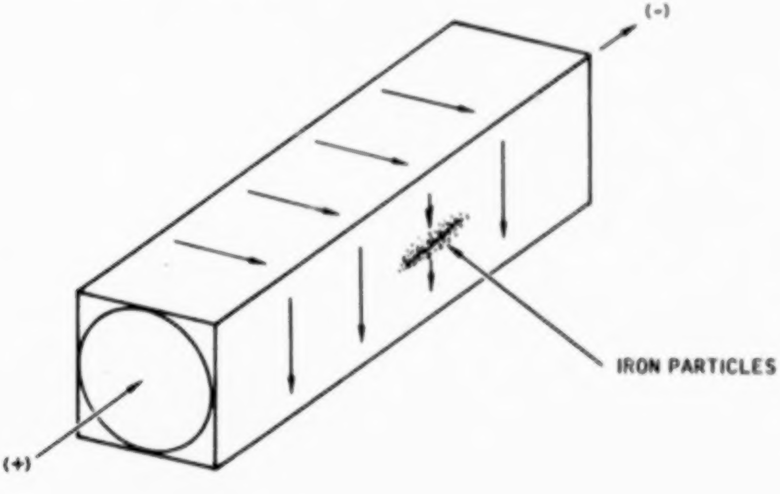
Remember, iron particles will only be attracted where there is flux leakage. The circular magnet had no poles and thus no flux leakage. Your answer is incorrect.

Turn to page 2-16.

You are absolutely right. Iron particles would not be attracted to the circular magnet. Iron particles would only be attracted where there are poles with flux leakage. If the circular magnet had a crack in it, iron particles would be attracted at the flux leakage.



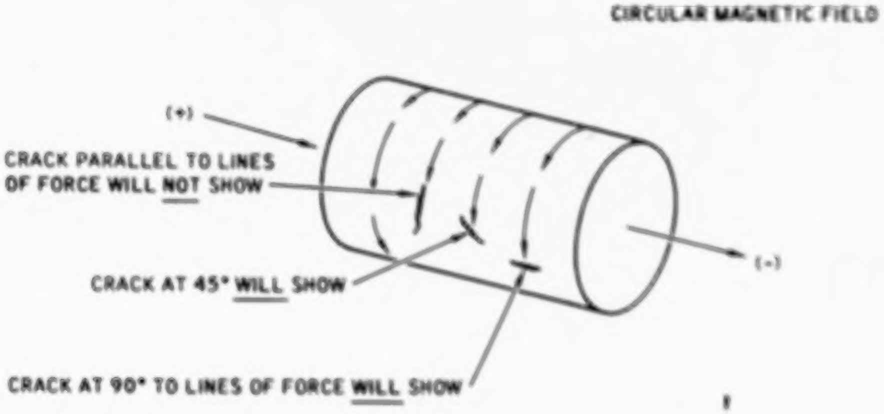
And that is exactly how cracks are located with magnetic particle inspection. If our square steel bar has a crack in the surface 90° to the direction of the lines of force within the bar, iron particles will be attracted to the crack.



The crack in the bar has caused a north and south pole. Some of the lines of force have been forced to the surface creating FLUX LEAKAGE. The flux leakage attracts the iron particles.

Turn to the next page.

CIRCULAR MAGNETIZATION will detect cracks that are between forty-five and ninety degrees to the lines of force.


CIRCULAR MAGNETIC FIELD
(+)
CRACK PARALLEL TO LINES OF FORCE WILL NOT SHOW
CRACK AT 45° WILL SHOW
CRACK AT 90° TO LINES OF FORCE WILL SHOW
(-)

The crack that runs crosswise 90° to the lines of force will have flux leakage and will attract iron particles. The crack at 45° will also have flux leakage and will attract iron particles.

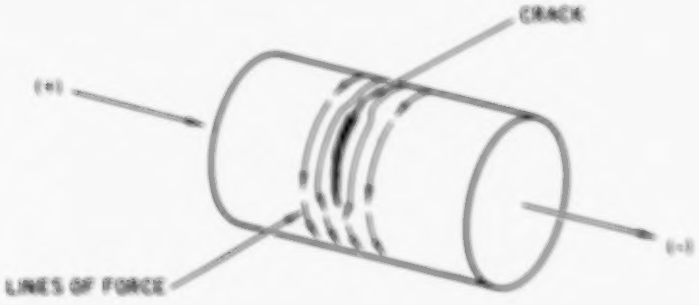
The crack that runs parallel to the lines of force does not present enough of the crack area to disrupt the lines of force and will not cause flux leakage. The lines of force tend to remain in the metal and squeeze around this crack.

The crack that runs parallel to the lines of force will not attract iron particles. Which of the following explains why this is so?

The lines of force jump through the crack	Page 2-18
No poles or flux leakage exist at the crack	Page 2-19
The crack is at 90° to the lines of force	Page 2-20

From page 2-17

The lines of force do not jump through the crack. Let's enlarge our view of the crack that lies parallel to the lines of force.

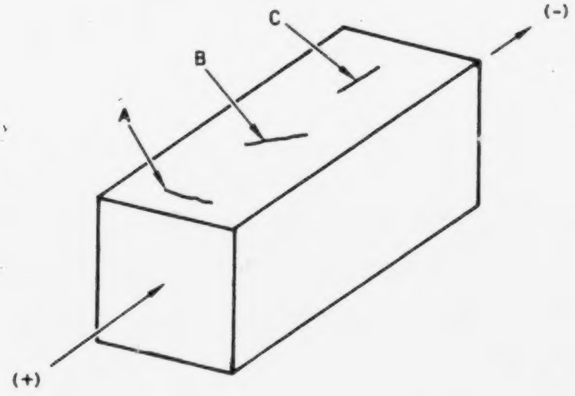


Notice how the lines of force bend around the crack. Since the lines of force are traveling in the same direction as the crack, there is very little area of the crack to force the lines of force out of the metal. The lines of force simply bend a little and remain in the metal.

Return to page 2-17 and try again.

Correct. There will be no flux leakage if there are no north and south poles. Therefore, iron particles will not be attracted. Any cracks that are parallel with the lines of force will not attract iron particles.

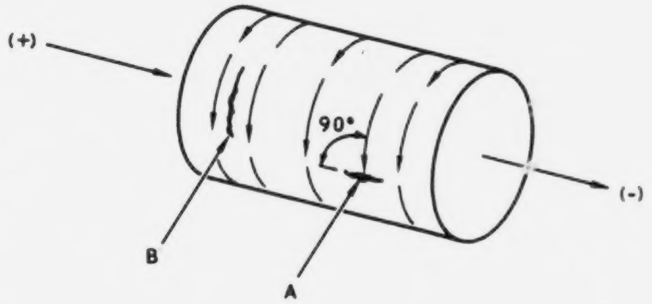
Here is our steel bar again.



If the steel bar is circularly magnetized, which of the cracks (A, B, or C) will NOT attract iron particles?

A	Page 2-21
B	Page 2-22
C	Page 2-23

You must be looking at the wrong crack. Let's take another look.

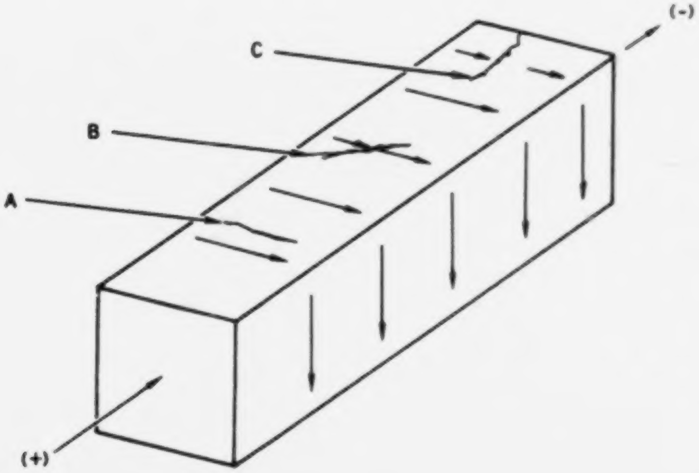


Notice that crack A cuts across (90° to) the lines of force. Crack B does not cut across any of the lines of force. Crack B runs in the same direction as the lines of force. In other words, crack B runs parallel to the lines of force.

Return to page 2-17 and select another answer.

From page 2-19

Excellent. That's right. Crack A will not attract iron particles.



Crack A is parallel to the lines of force and will not have magnetic poles or flux leakage.

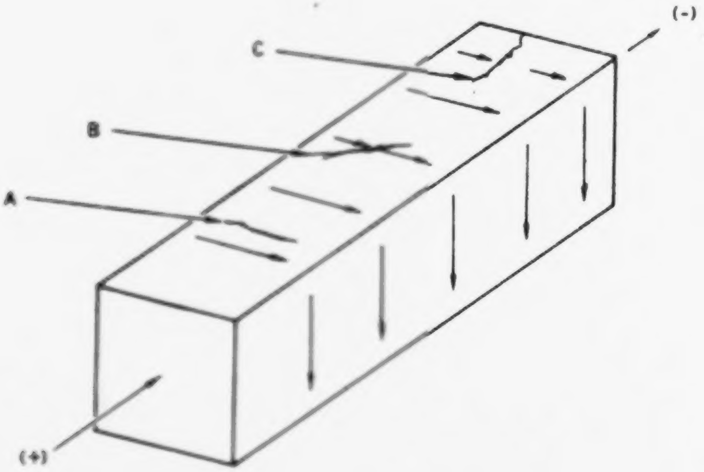
Cracks B and C will develop magnetic poles and flux leakage. Because of this, they will attract iron particles at the cracks.

Cracks that are crosswise, 90° to the lines of force, cause more lines of force to be forced out at the surface which gives a greater amount of flux leakage. Cracks can be up to 45° to the lines of force and still have enough flux leakage to adequately attract iron particles.

Now let us see how all of this is applied to your work in the lab.

Turn to page 2-24

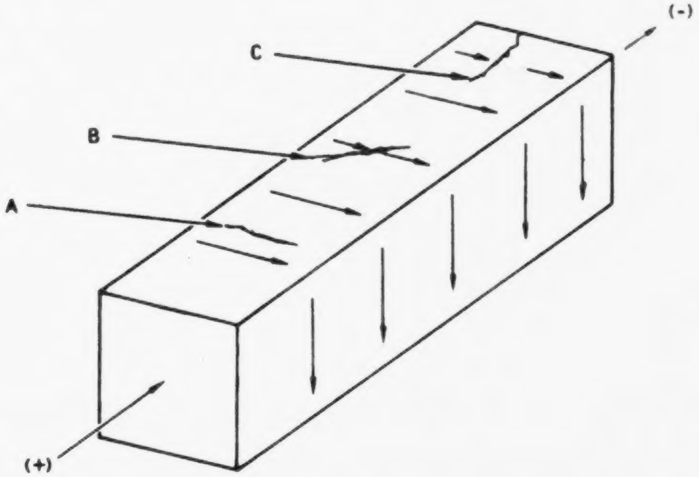
You think that crack B will not attract iron particles. Let's look at the steel bar again.



Remember that the magnetizing current runs from (+) to (-) left to right. Using the right-hand rule, the magnetic field is set up as shown by the arrows. Crack A is parallel to the lines of force (does not cut across any of the lines of force) so it will not form magnetic poles. Cracks C and B are at 90° and 45° to the lines of force and will form magnetic poles with flux leakage since they will disrupt the lines of force.

Return to page 2-19 and try once again.

You think that crack C will not attract iron particles and that is incorrect. Let's look at the steel bar again.

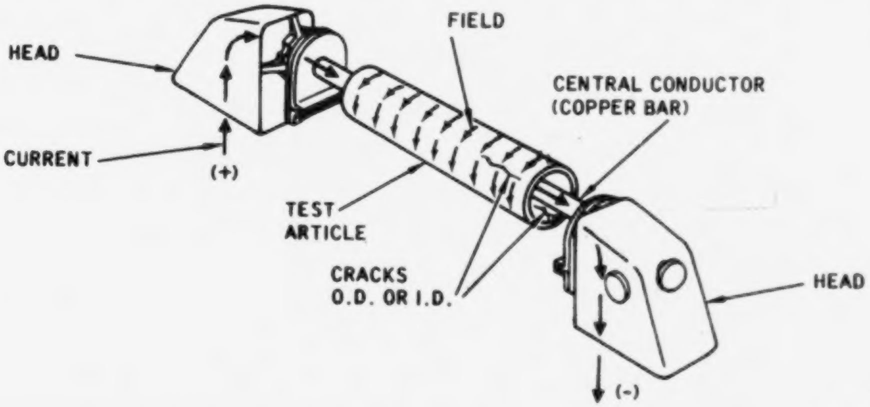


Remember that the magnetizing current runs from (+) to (-), left to right. Using the right-hand rule, the magnetic field is set up as shown by the arrows. Crack A is parallel to the lines of force (does not cut across any of the lines of force) so it will not form magnetic poles. Cracks B and C are at 90° and 45° to the lines of force and will form magnetic poles with flux leakage since they cut across the lines of force.

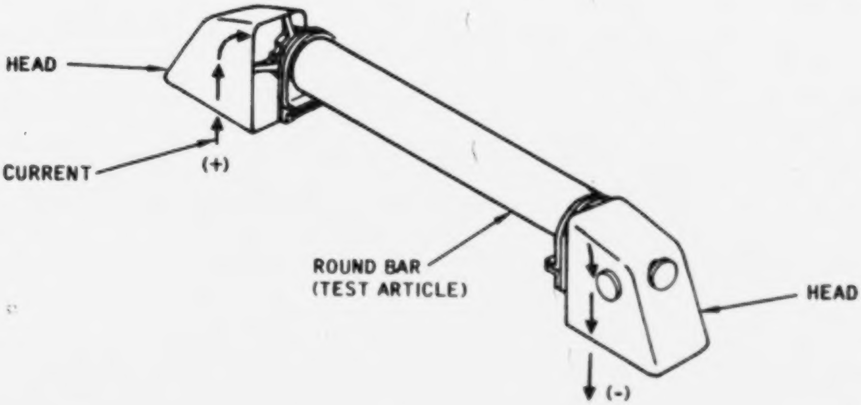
Return to page 2-19 and try once again.

From page 2-21

In practice, CIRCULAR MAGNETIZATION is accomplished in two ways.


FIELD
HEAD
CENTRAL CONDUCTOR
(COPPER BAR)
CURRENT
(+)
TEST
ARTICLE
CRACKS
O.D. OR I.D.
HEAD
(-)

First, by passing electric current through a central conductor as in the drawing above: and second, by passing electric current through the test article itself as in the drawing below.


HEAD
CURRENT
(+)
ROUND BAR
(TEST ARTICLE)
HEAD
(-)

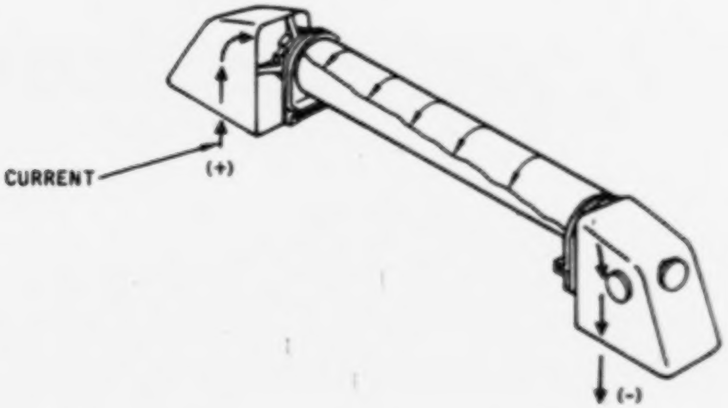
Passing electric current directly through the test article is called a head shot and causes a circular-magnetic field within the test article.

If the round rolled bar had a seam in it, do you think that iron particles would be attracted to the seam?

Yes .... Page 2-25

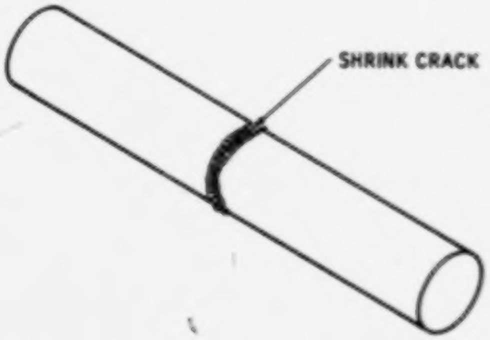
No .... Page 2-26

Right. Iron particles would be attracted to the seam, and we would have an indication like this.



The seam is crosswise or transverse to the lines of force and would have flux leakage to attract the iron particles.

Suppose the round steel bar were welded together in the middle like this.



Would this shrink crack attract iron particles if the bar were circularly magnetized between the heads?

No .... Page 2-27
Yes .... Page 2-28

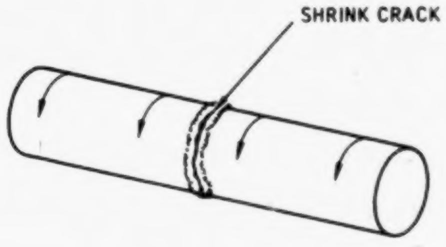
You have probably forgotten what a seam is, so let's take a look at one.

Remember, a seam runs along the length of the bar. Apply the right-hand rule and you should be able to answer the question correctly.

Return to page 2-24 and try again.

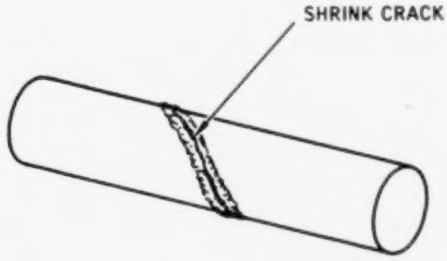
From page 2-25

Of course not. The shrink crack would not attract iron particles.



The shrink crack at the weld runs parallel to the lines of force and would not form flux leakage to attract iron particles.

Here is our round steel bar with another weld in the middle at an angle of approximately 45° to the lines of force.



If this part were circularly magnetized, do you think that iron particles would be attracted to a shrink crack in this weld?

No .... Page 2-29

Yes .... Page 2-30

From page 2-25

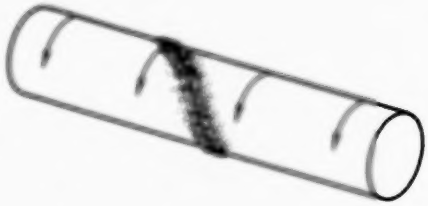
You missed on that one, so let's review the facts in the case.

1. The shrink crack is oriented around the circumference of the bar.
2. By applying the right-hand rule, we know that the lines of force would be oriented around the circumference of the bar.
3. Therefore, the crack is in the same direction as the lines of force.
4. Cracks that lie parallel to the lines of force will not form poles or flux leakage.
5. Since no flux leakage would be formed, iron particles would not be attracted to the crack.

Turn to page 2-27

From page 2-27

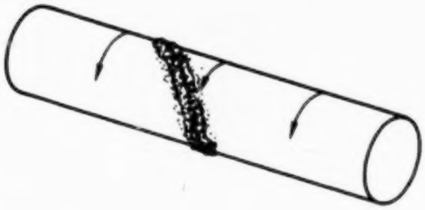
We caught you napping that time.



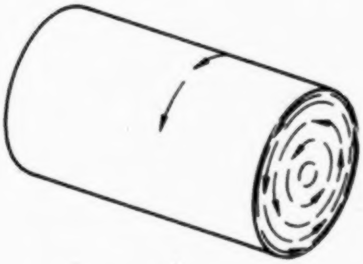
That shrink crack cuts across the lines of force at a 45° angle and would attract iron particles.

Turn to page 2-30

Yes is right. Iron particles would be attracted to that shrink crack because it was approximately 45° to the lines of force.



When an article is magnetized between the heads, the magnetic field is strongest near the surface of the article. The magnetic field increases from zero at the center of the article to a maximum at the surface.



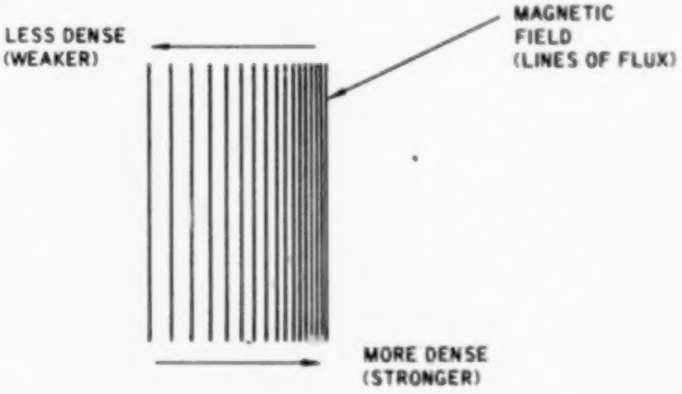
This is an end view of the round steel bar showing the magnetic field. The strength of a magnetic field is often referred to as FLUX DENSITY. In this end view, you can see that the lines of flux are crowded together near the surface. This shows that the flux density is greatest at the surface. The increased flux density would have what effect on flux leakage at a crack?

Decreased flux leakage .... Page 2-31

Increased flux leakage .... Page 2-32

You feel that increased flux density would decrease flux leakage at a crack. No, that is not the case. Let us explain flux density more thoroughly.

Lines of force are the same as lines of flux. Where these lines of flux are crowded together, the magnetic field will be the strongest. The strength of a magnetic field is known as its flux density. The more that lines of flux are crowded together, the greater will be the magnetic field flux density or strength.

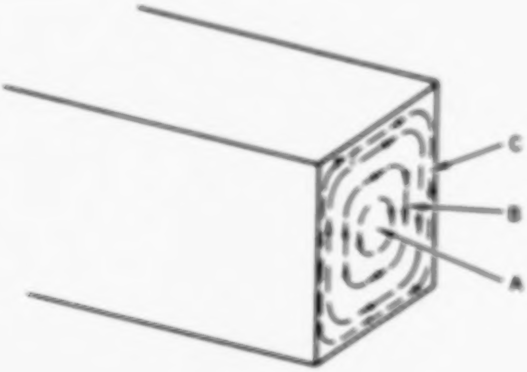


With circular magnetization between the heads, the flux density (magnetic field strength) is greatest near the surface. Therefore, if the flux density is greatest near the surface, flux leakage would be greater at a crack.

Turn to page 2-32

That's right. The increased flux density would increase flux leakage at a crack. Since the flux density is greatest near the surface, the magnetic field strength is also greatest in this area.

As a general rule it can be said that, with circular magnetization between the heads, flux density will be greatest at the surface. This is particularly true with simple, uncomplicated parts such as the round steel bar. However, trial and error methods must be used when magnetizing very complicated parts.



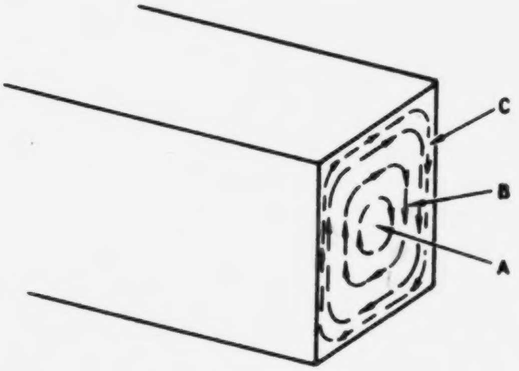
If you were circularly magnetizing this steel bar between heads, at which point (A, B, or C) would you expect the flux density to be greatest?

A .... Page 2-33

B .... Page 2-34

C .... Page 2-35

You selected point A. Flux density would not be greatest at point A. Point A is in the center and the magnetic field strength is zero there.



The strength of the magnetic field increases from zero at the center of the article to a maximum near the surface.

Return to page 2-32 and select another answer.

From page 2-32

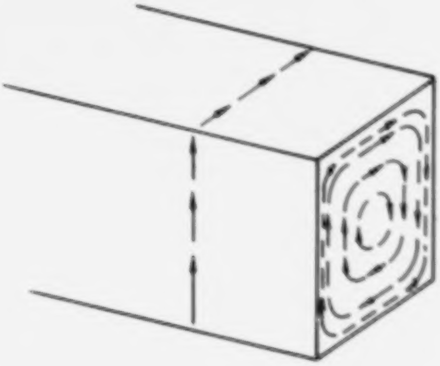
You selected point B. Flux density would not be greatest at point B.

The square steel bar is not one of those complicated articles that we mentioned. Magnetizing that bar between the heads would cause the magnetic field to be strongest at the surface. The strength of the magnetic field would increase from zero at the center of the article to a maximum at the surface.

Return to page 2-32 and select another alternative.

From page 2-32

Excellent. Flux density would be greatest at point C. As a general rule, with circular magnetization between the heads, flux density will be greatest at the surface.

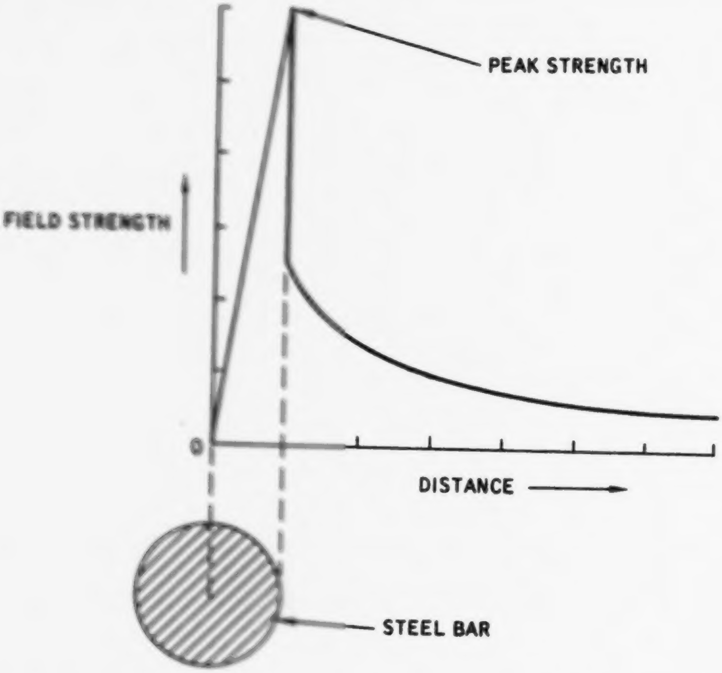


The magnetic field increases from zero at the center of the article to a maximum at the surface. This is a general rule that applies to uncomplicated articles.

Turn to the next page.

From page 2-35

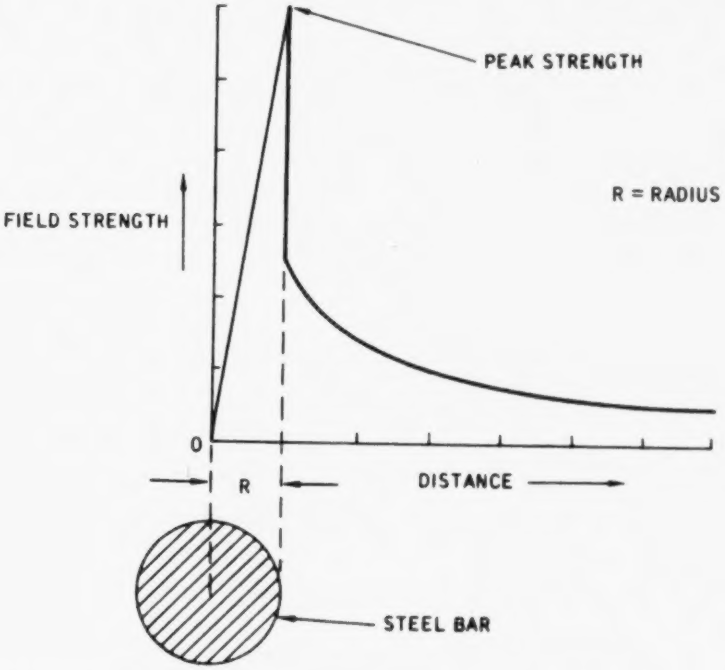
Distribution of the magnetic field within an article being magnetized between the heads can be illustrated graphically. Here is what happens to our round steel bar.



Here you can see that the field strength is zero at the center of the article. The flux density increases evenly until it reaches peak strength at the surface. What happens to the flux density just outside the surface of our round steel bar?

Flux density remains the same .... Page 2-37
Flux density decreases .... Page 2-38
Flux density drops rapidly .... Page 2-39

You feel that the flux density would remain the same just outside the surface of our round steel bar. Let's look at the diagram again.

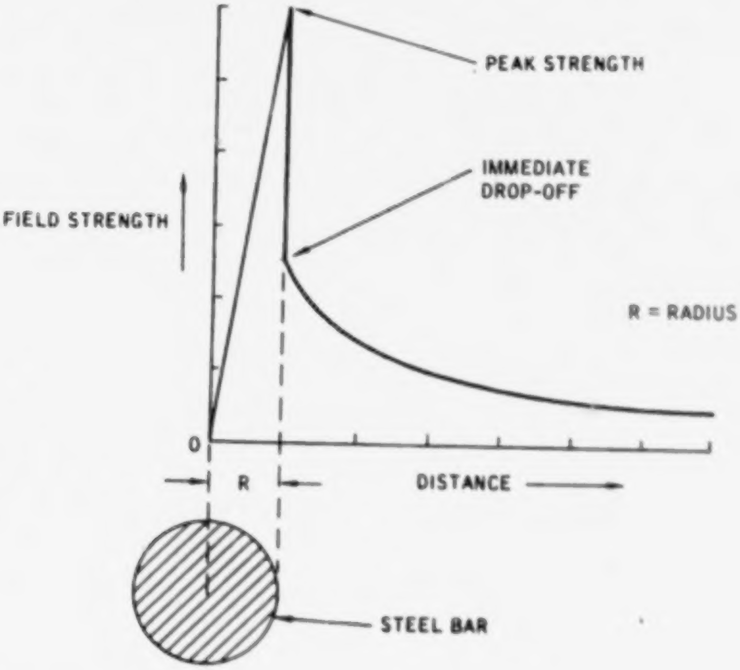


The vertical scale on the left of the chart is scaled to show the magnetic field strength or flux density. The scale across the bottom of the chart shows distance from the center of the steel bar. If the flux density remained the same just outside the surface of the steel bar, a line would have to be added at the peak strength point shown by the arrow. So you see, the flux density does not remain the same just outside the surface of the round steel bar.

Return to page 2-36 and study the problem again.

From page 2-36

You feel that the flux density decreases just outside the surface of the round steel bar. Yes it decreases but very abruptly and to a relatively negligible amount. Most of it drops off immediately as shown here.

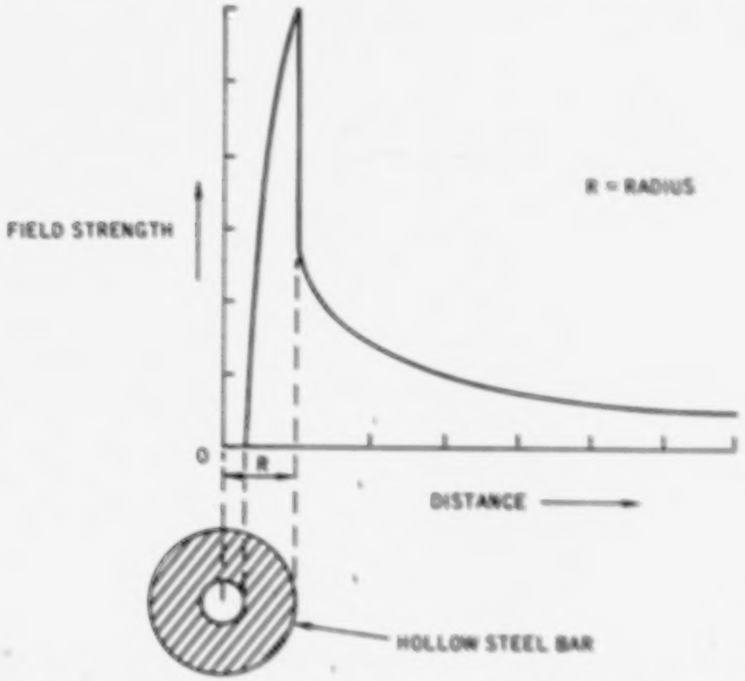


So you see, the flux density drops rapidly just outside the surface of the steel bar.

Turn to page 2-39

That's right. Flux density drops rapidly just outside the surface of the round steel bar. Most of it is lost immediately and the remainder is negligible. However, at the surface of the article, flux density reached its peak strength.

If we pass electric current through a hollow steel bar as in magnetization between the heads, the magnetic field distribution in the bar can be shown graphically as follows.



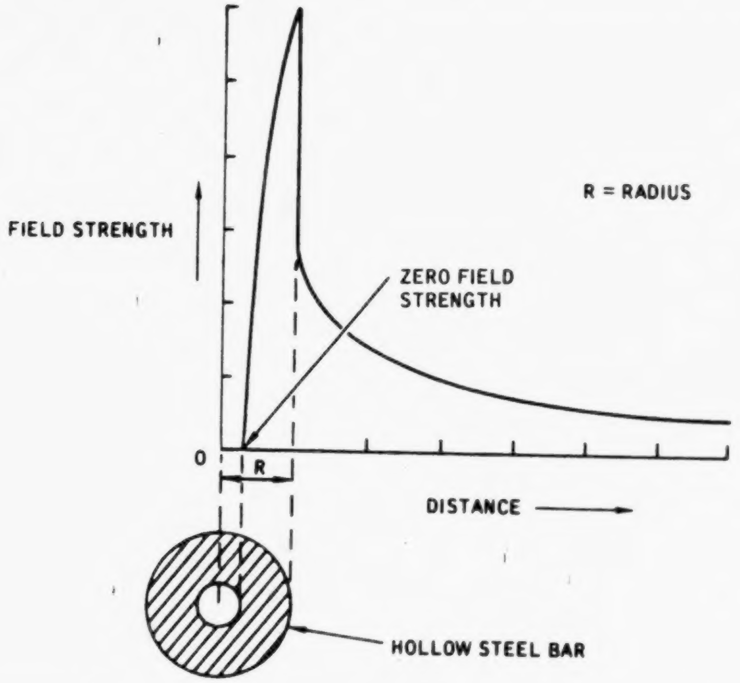
When the hollow steel bar is magnetized between the heads, what do you think is the area of greatest flux density in this case?

In the center of the hole in the article ....Page 2-40

At the outside surface of the article ....Page 2-41

At the inner surface (I. D.) of the article....................................Page 2-42

You feel that the area of greatest flux density in the hollow steel bar is the center of the hole in the bar. Actually, there would be no magnetic field anywhere in that hole. You may have been mislead by that dashed line to the center of the hole. It was placed there to show only the radius of the article. Let's look at the chart again.



We have added an arrow here to show the point of zero field strength.

Return to page 2-39 and pick out the point of greatest flux density.

From page 2-39

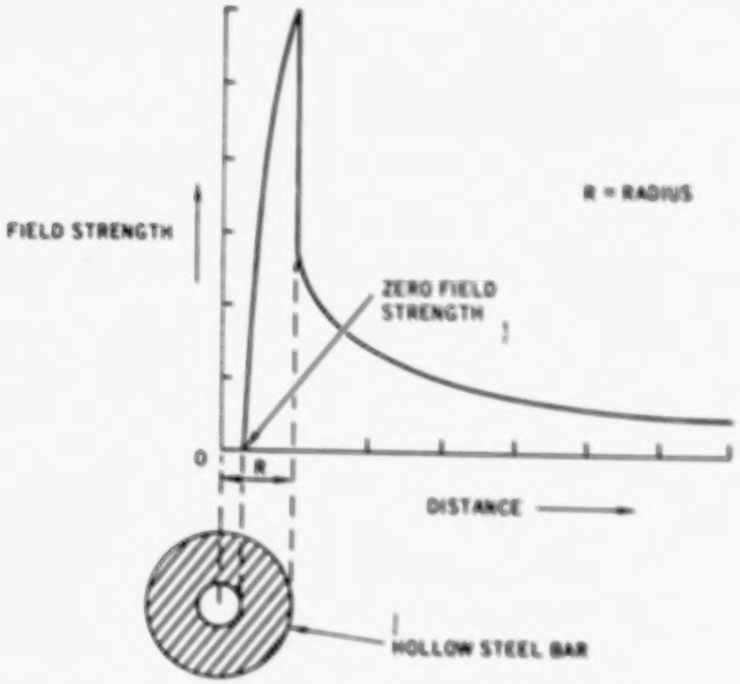
Absolutely. The flux density would be greatest at the outside surface of the hollow steel article.

As a general rule, it can be said that circular magnetization between the heads causes flux density to be greatest at the surface of the article. This is true with simple, uncomplicated articles. However, trial and error methods must be used when magnetizing very complicated articles.

The point we are making here is that "between the heads" circular magnetization of a hollow article will result in strong magnetization at the outer surface. However, magnetization at the inner surface will be zero and defects there would not attract iron particles.

Turn to page 2-43

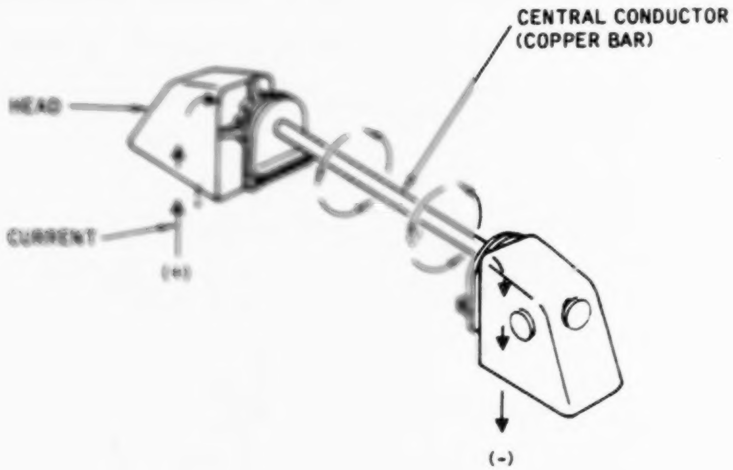
You feel that the area of greatest flux density would be at the inner surface (I.D.) of the hollow steel bar. No, the magnetic field distribution in the hollow bar is about the same as in the solid steel bar. The only difference is that the point of zero field strength in this example is at the inner surface (I.D.) of the article.



The arrow we have added, indicating zero field strength, should give you a clue to the correct answer.

Return to page 2-39 and try again.

Let's expand the idea of CIRCULAR MAGNETIZATION using a central conductor. When electricity flows through an electrical conductor such as a copper wire, a magnetic field is established around the wire. In practice, we use this principle by putting a copper bar between the heads.



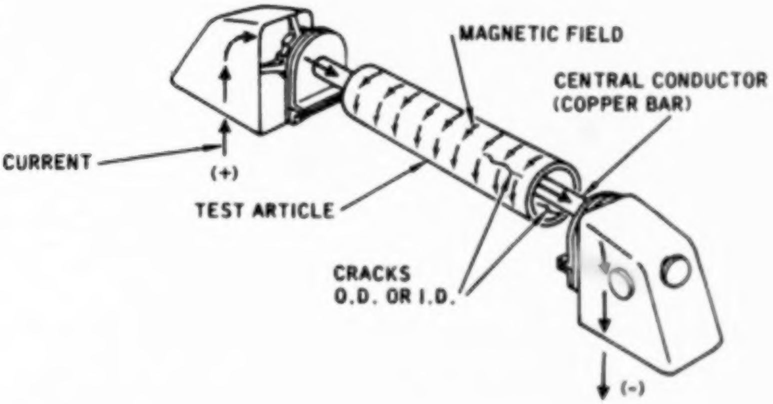
The copper bar is used as part of the equipment. When electricity flows through the copper bar, a magnetic field is established around the bar. The copper bar is called a CENTRAL CONDUCTOR.

The central conductor is used to establish a magnetic field in cylindrical objects such as steel tubing and short hollow cylinders. It is most effective when used this way because the magnetic field is strongest at the surface of the central conductor.

Turn to the next page.

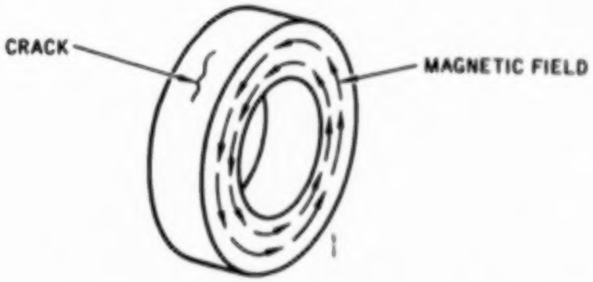
From page 2-43

The magnetic field around the CENTRAL CONDUCTOR (copper bar) enters the cylindrical object and creates a circular magnetic field within the object. Since flux density is greatest at the surface of the central conductor, the strongest magnetic field will be induced in the article by allowing the article to lie on the central conductor. Unlike between the heads magnetizing, the use of the central conductor will create magnetic flux on the inner surface of the article as well as the outer surface. In fact, flux density is greatest on the inner surface and, depending on the wall thickness, something less on the outer surface.



The circular magnetic field set up by the CENTRAL CONDUCTOR will detect cracks that are crosswise to the lines of flux as in the example above. These cracks cause flux leakage which attracts iron particles.

Would iron particles be attracted to a crack that runs parallel to the lines of flux like this one?



Yes .... Page 2-45

No .... Page 2-46

From page 2-44

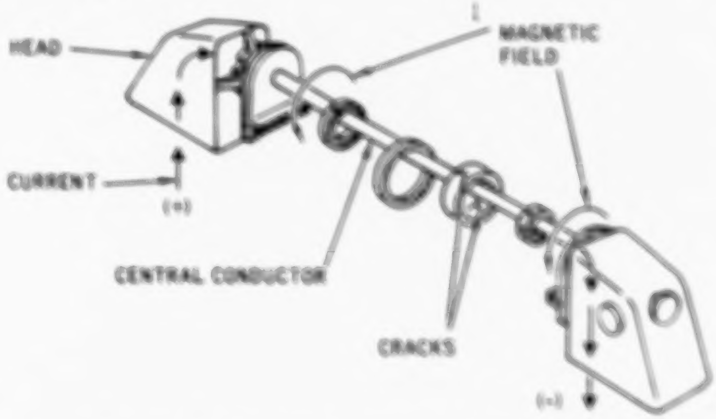
You are probably confused because we are using the central conductor. But the rules don't change just because we changed the method.

In this case, the crack is in the same direction as the lines of flux. As a result no flux leakage was formed at the crack so iron particles would not be attracted at the crack.

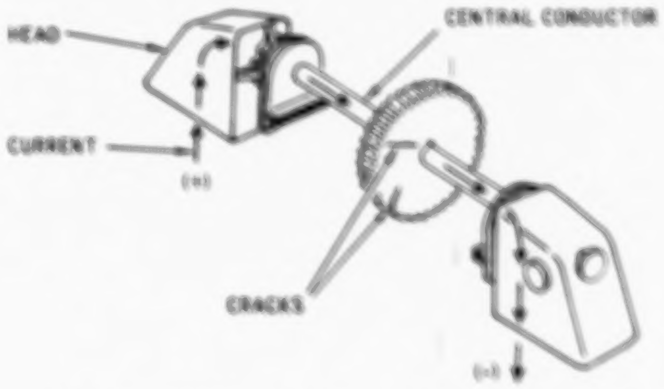
Turn to page 2-46

No is correct. A crack that runs parallel to the lines of flux would not cause flux leakage and would not attract iron particles.

The CENTRAL CONDUCTOR is used to magnetize many different types of hollow articles. Its greatest advantage is that the flux density is greatest at the surface of the bar and will induce a strong magnetic field which will locate cracks both on the inner and outer surfaces as shown here.


HEAD
MAGNETIC FIELD
CURRENT
(+)
CENTRAL CONDUCTOR
CRACKS
(-)

In the example below, do you think circular magnetization with the CENTRAL CONDUCTOR would attract iron particles to the cracks in this gear?

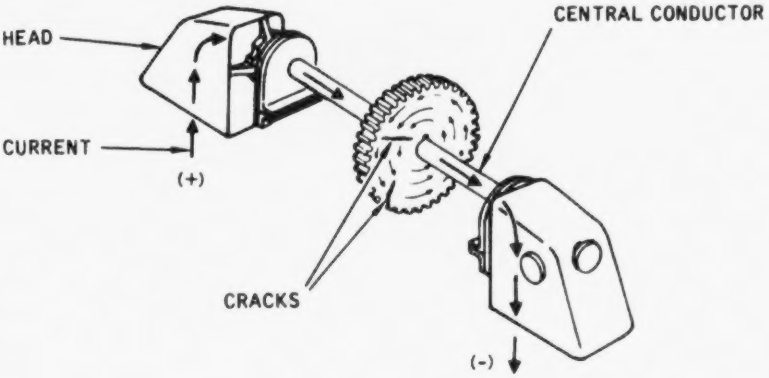

HEAD
CENTRAL CONDUCTOR
CURRENT
(+)
CRACKS
(-)

Yes .... Page 2-47

No .... Page 2-48

From page 2-46

Yes sir. Iron particles would be attracted to the cracks in the gear.

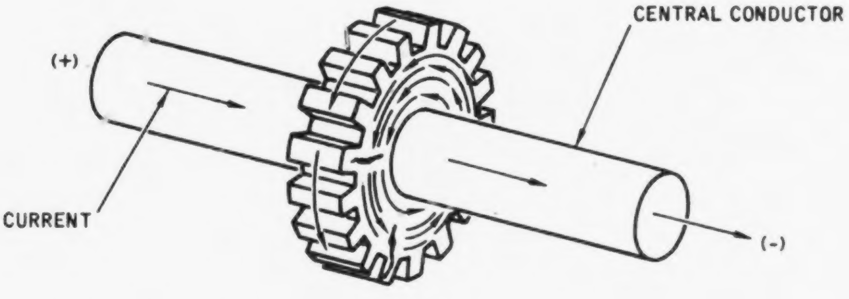


The cracks run crosswise (90°) to the lines of flux and would cause flux leakage. If we dust iron particles on the gear, they would be attracted to those cracks.

It is important to remember that flux density is greatest at the surface of a central conductor. Therefore, hollow articles should be threaded on the central conductor and allowed to come in direct contact with it to obtain the strongest magnetic field.

Turn to page 2-49.

Use of the central conductor is a little tricky, so let's look at the lines of flux set up in the gear.



Up to now, we have been looking only at the outer surface of bars. With use of the central conductor, we can now look at the ends or flat surfaces of the articles. The circular field is present in the flat end surfaces of the gear as well as in the outer rim.

Take another look at the illustration on page 2-46 and try the question again.

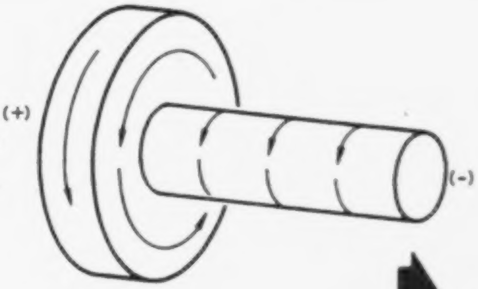
From Page 2-47

1. Review:

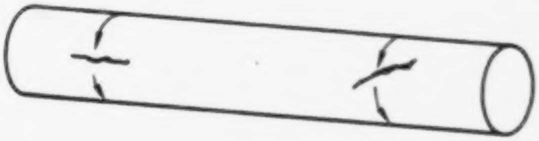
The current through a wire always flows from ________________ to negative.

6. non-magnetic

7. Whenever current is passed through any magnetic article, a circular field is produced ___________ the article.



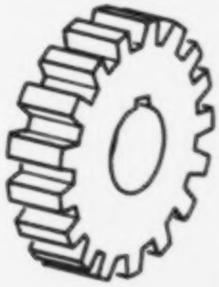
12. circularly magnetize



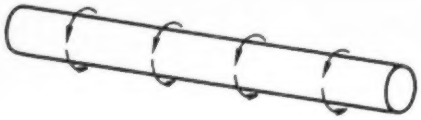
13. Any crack that runs from ________ to 90° across the magnetic field will form flux leakage.

18. circularly, central conductor

19. If we suspected that this gear might have cracks on either side, we would magnetize it using the __________________ __________________ method.

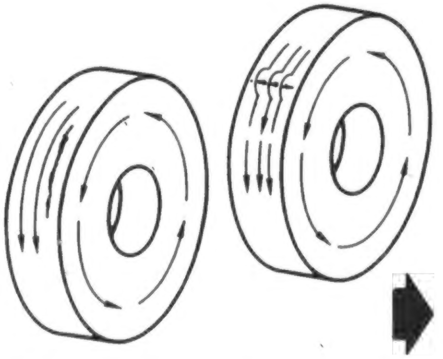


1. positive



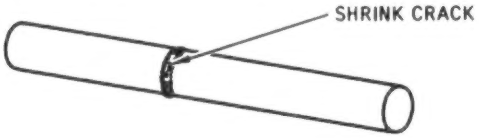
2. When current flows along a copper wire, it produces a____________________ ________________that surrounds the wire.

7. in (inside)



8. Iron particles will not be attracted to a circular field except where there is____________________ ________________.

13. 45°



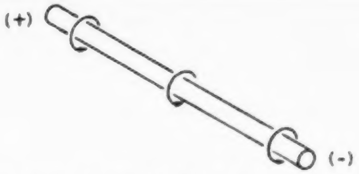
14. Suppose we suspected that this weld had a shrink crack in it. Would a circular field cause flux leakage at this crack?______

19. central conductor

FIELD STRENGTH → FLUX DENSITY

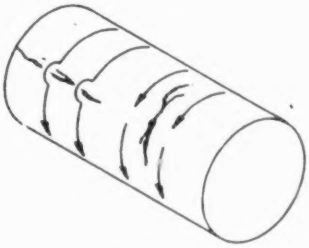
20. A strong magnetic field is said to have greater flux density than a weak magnetic field. The higher the field strength the greater the____________ ______________________.

2. magnetic field



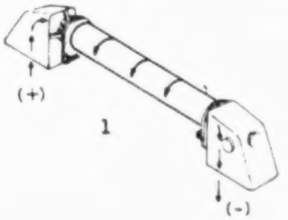
3. The magnetic field produced by the current flowing through this wire is in a c________________________direction.

8. flux leakage

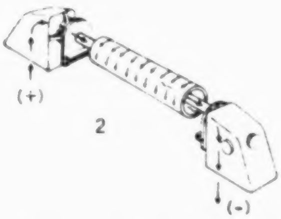


9. A crack that runs crossways or at least 45° to the lines of force will cause____________ ________________________.

14. no



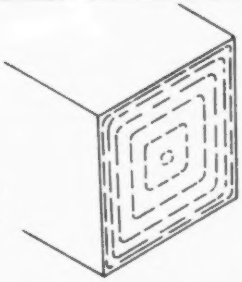
1



2

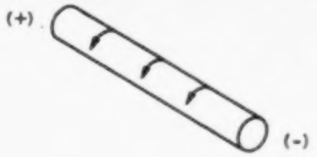
15. A circular magnetic field can be established in an article in two ways: 1) by passing current directly through the article, and 2) by passing current through a________________conductor.

20. flux density



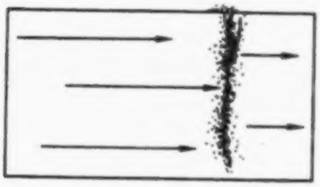
21. When passing current directly through the bar (head shot), flux density is greatest at the________________of the bar.

3. circular



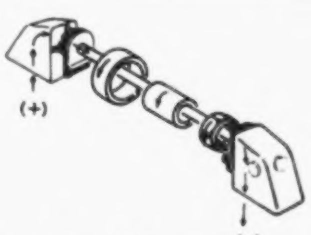
4. When current flows along a steel bar, it produces a __________ __________ field in the bar.

9. flux leakage



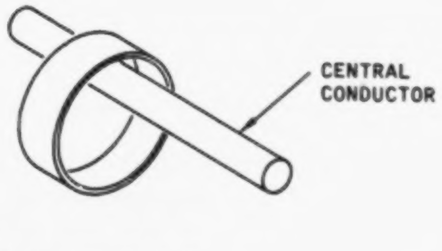
10. A crack that runs crossways to the lines of force will cause flux leakage which__________ iron particles to the crack.

15. central



16. The central conductor method is used to circularly magnetize different types of h__________ articles such as tubes, rings, and nuts.

21. surface

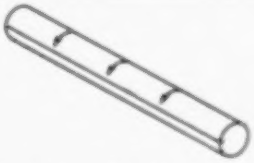


22. When using the central conductor, flux density is greatest at the __________ of the conductor.

4. circular magnetic

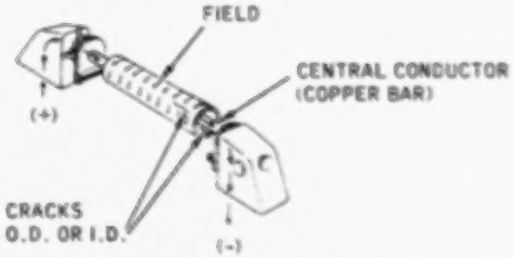
5. The circular magnetic field is formed inside the bar because the steel is a ______________________ material.

10. attracts



11. Here is a bar with a seam in it. If the bar were circularly magnetized, the seam would run ______________________ to the lines of force.

16. hollow



17. When a central conductor is used to circularly magnetize an article, both ends of the article can be inspected, as well as the ____________ and outside of the hollow article.

22. surface

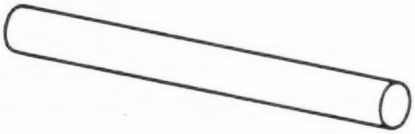
23. Because flux density is greatest at the surface of the central conductor a hollow article will have greatest flux density at the ________ surface of the article.

5. magnetic

6. The circular magnetic field is formed around a copper central conductor because the conductor is a ______________________ material.

Return to page 2-49, frame 7.

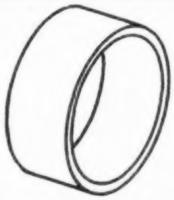
11. crossways (at 90°)



12. Suppose that we suspected that there might be a seam in this bar. To find out, we would _______________ _______________ the bar.

Return to page 2-49, frame 13.

17. inside



18. If we were to inspect this ring, inside and out, for possible seams, we would _______________ magnetize it using the __________ _______________.

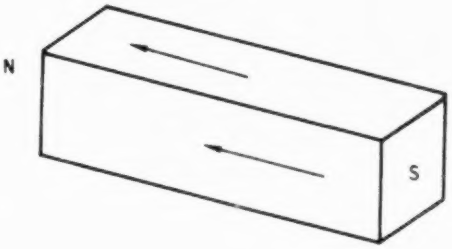
Return to page 2-49, frame 19.

23. inside

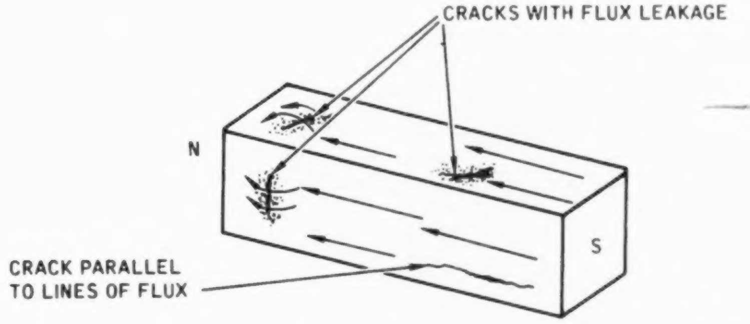
24. TURN TO THE NEXT PAGE.

LONGITUDINAL MAGNETIC FIELD

In a longitudinal magnetic field, an article is magnetized lengthwise. The bar magnet is a good example of a longitudinal magnetic field.



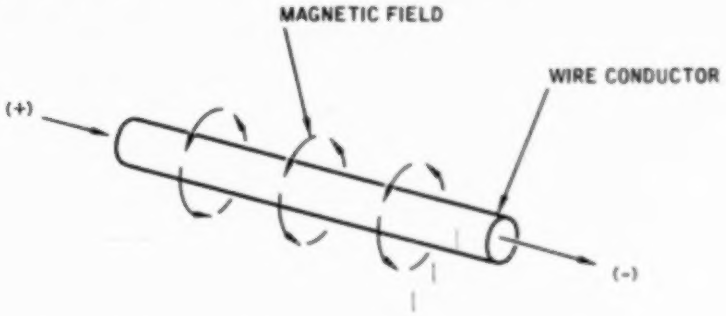
The magnetic lines of flux in the bar magnet go through the length of the bar. You will recall that a crack which runs across 90° to, or at least 45° to the lines of flux, will cause flux leakage. The flux leakage will attract iron particles like this.



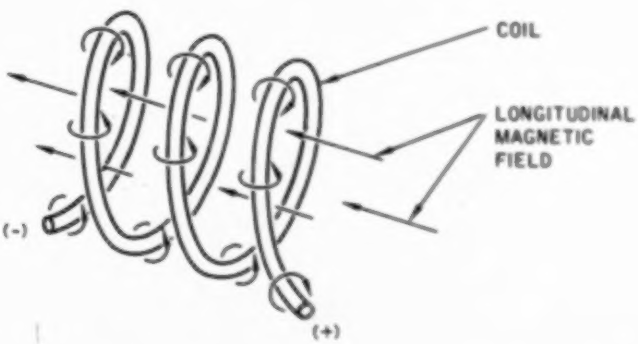
As you can see, a crack that runs parallel to the lines of flux will not cause flux leakage. Now let us see how an article can be longitudinally magnetized.

Turn to the next page.

Longitudinal magnetization also uses the principle that electric current passing through a copper wire forms a magnetic field around the wire.



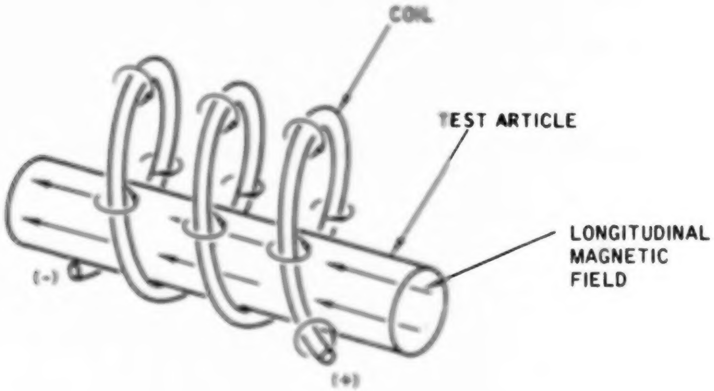
When the copper wire is wound into a coil, the lines of flux around each turn of the coil combine with those of each of the other turns in the coil. This increases the flux density and gives a total force in a longitudinal direction.



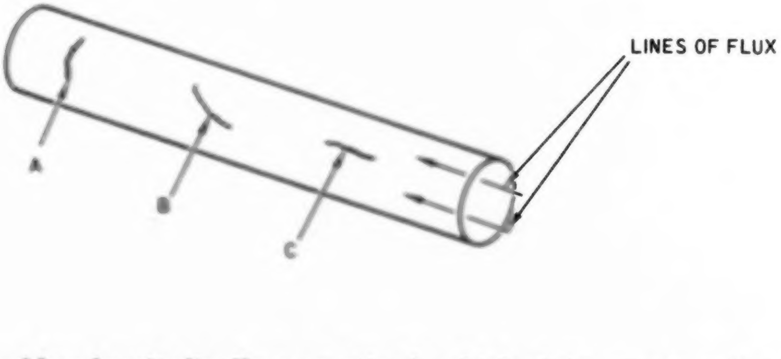
The flux density or strength of the magnetic field is greatest at the surface of the copper wire. Therefore, flux density of the total longitudinal magnetic field will be greatest at the inside surface of the coil.

Turn to the next page.

When we place an article inside the coil through which electric current is passing, a longitudinal magnetic field is set up in the article.


COIL
TEST ARTICLE
LONGITUDINAL MAGNETIC FIELD
(-)
(+)

The longitudinal magnetic field will cause flux leakage at cracks which run crosswise to the lines of flux. Cracks running up to 45° to the lines of flux will also have flux leakage.


LINES OF FLUX
A
B
C

With this round bar longitudinally magnetized, which of the cracks will attract iron particles?

A . . . . Page 2-58

A and B . . . . Page 2-59

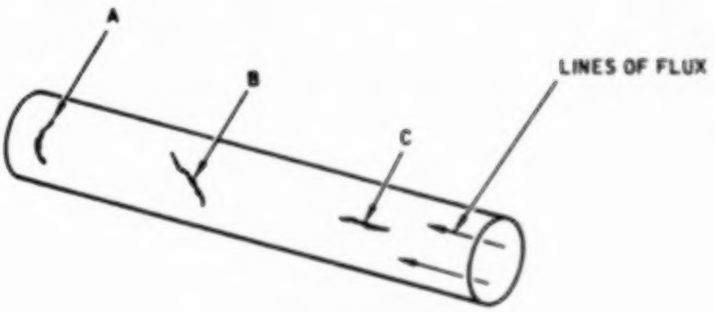
B and C . . . . Page 2-60

Yes, crack A will attract iron particles. It runs crosswise (90°) to the lines of flux and will have flux leakage.

One thing more to remember is that cracks up to 45° to the lines of flux will also have magnetic poles and/or flux leakage.

Return to page 2-57 and see if there isn't a more complete answer.

Right. A and B was the best selection.



Crack A is crosswise (90°) to the direction of the lines of flux and would have flux leakage to attract iron particles to the crack. Crack B is about 45° to the lines of flux and would also have flux leakage to attract iron particles.

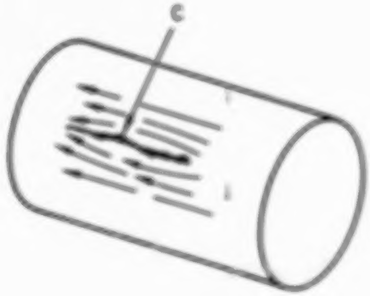
Crack C is parallel to the lines of flux and would not disrupt the lines of flux and cause flux leakage. The lines of flux follow the path of least resistance and squeeze around crack C, staying in the metal.

Now, let us see how the longitudinal magnetic field is used in practice.

Turn to page 2-61.

You are half right. Crack B will attract iron particles because it is 45° to the lines of flux.

Crack C will not attract iron particles. It is parallel to the lines of flux and will not disrupt them.

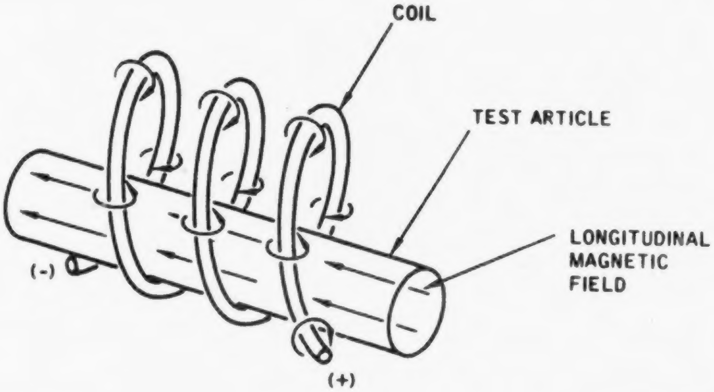


The lines of flux tend to follow the path of least resistance and that is - to stay in the metal. Therefore, the lines of flux squeeze around crack C and do not cause flux leakage.

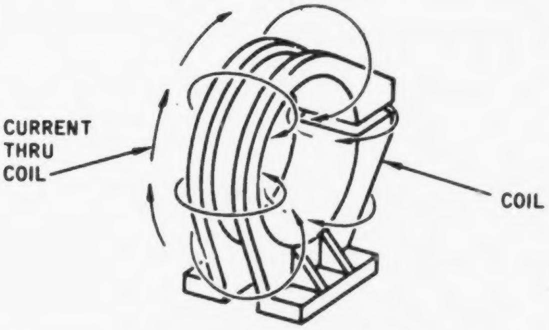
Return to page 2-57 and pick a better answer.

From page 2-59

In practice we use a coil similar to the one we have been using as an example to produce a longitudinal magnetic field.


COIL
TEST ARTICLE
LONGITUDINAL MAGNETIC FIELD
(-)
(+)

However, the coils are pushed together and placed inside a housing.


CURRENT THRU COIL
COIL

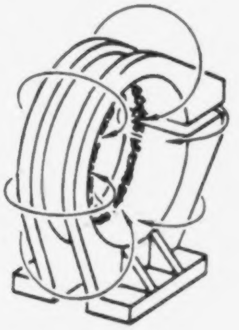
The magnetic field is strongest near the inside surface of the coil where the flux density is greatest. Flux density decreases toward the center of the coil where it is zero.

If you were to longitudinally magnetize a round, steel bar in the coil, where would you place the bar to get the greatest flux density?

Near the center of the coil . . . . Page 2-62

Near the inside surface of the coil . . . . Page 2-63

You missed the point. Let's look at that coil again.



The magnetic field is strongest near the inside surface of the coil as shown above by the arrows surrounding the coil. The shaded area shows where the field is strongest.

The point to be made here is that the magnetic lines of flux are concentrated near the inside surface of the coil. This concentration of lines of flux causes the magnetic field to be strongest near the inside surface of the coil. Toward the center of the coil, the lines of flux are not so close together. At the center of the coil, the magnetic field decreases to zero.

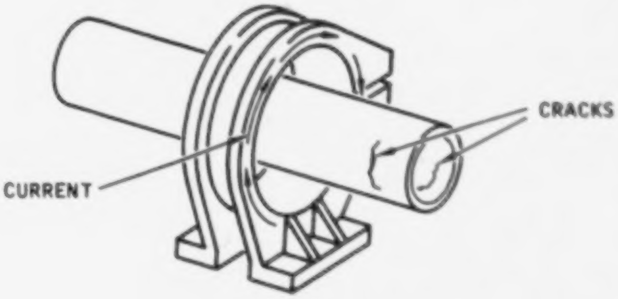
To longitudinally magnetize a round, steel bar in the coil, you would place the bar where the magnetic field is strongest: the area of greatest flux density near the inside surface of the coil.

Turn to page 2-63.

From page 2-61

Right. Flux density would be greatest near the inside surface of the coil. The magnetic field is strongest near the inside surface of the coil where the flux density is greatest. That is where the lines of flux are concentrated.

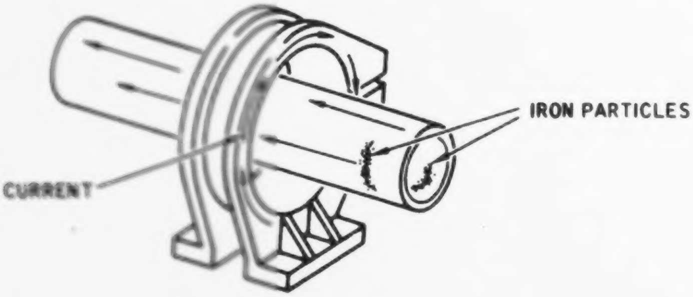
A longitudinal magnetic field can also be used to locate cracks in hollow, tube-like articles. The cracks must be crosswise or at least 45° to the lines of flux to attract iron particles to the crack.



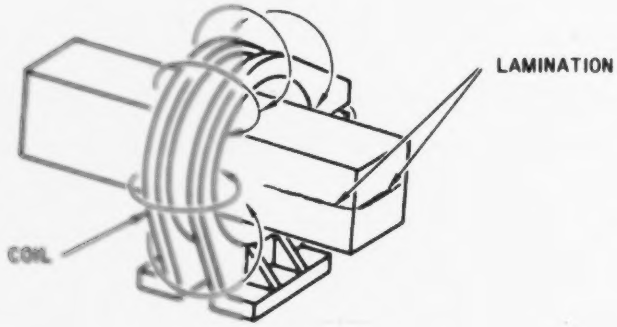
If we shoot electricity through the coil (coil shot) to longitudinally magnetize this tube, do you think that the crack on the outside and the crack on the inside would both attract iron particles?

Yes . . . . Page 2-64
No . . . . Page 2-65

That's right. Both cracks in the tubing would attract iron particles since they are crosswise (90°) to the lines of flux.


IRON PARTICLES
CURRENT

Below, a piece of iron plate is being longitudinally magnetized.


LAMINATION
COIL

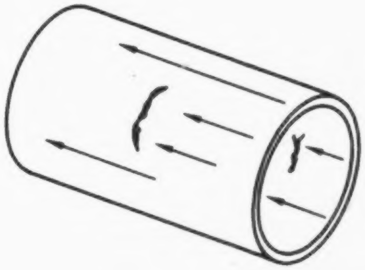
Do you think that iron particles would be attracted to the lamination if the article were longitudinally magnetized?

Yes . . . . Page 2-66

No . . . . Page 2-67

From page 2-63

You must have forgotten that any crack which cuts across the lines of flux will cause flux leakage. Let's add the longitudinal lines of flux to the article and see what we have.

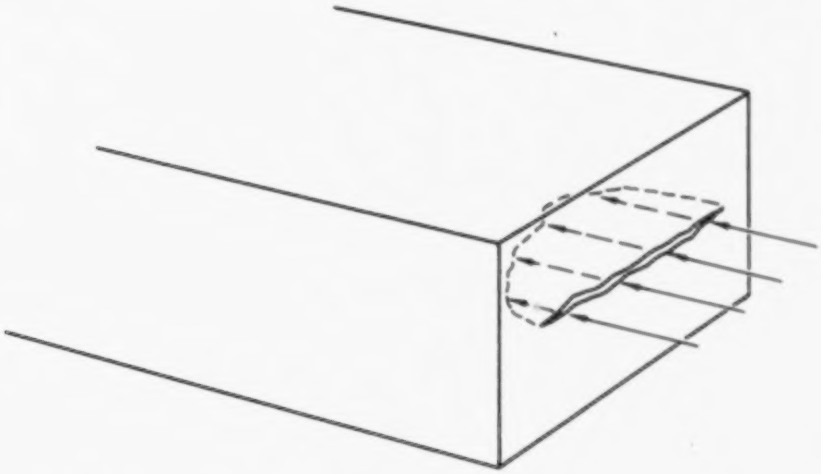


Here is an enlarged view of the longitudinally magnetized tube. The lines of flux are present on the inside surface of the tube as well as the outside.

Since the cracks cut across the lines of flux, iron particles will be attracted to both cracks.

Turn to page 2-64.

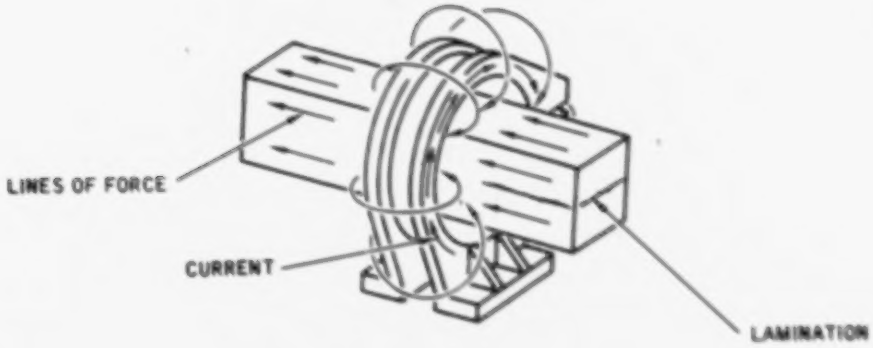
That is a tough one to lose, but iron particles would not be attracted at the lamination. Perhaps the lamination on the right end of the bar threw you since it could appear to be crosswise to the lines of flux. The problem here is that you are only seeing the top part of the lamination. Let's enlarge the view and take another look at it.



Notice that the lamination extends into the metal in the same direction as the lines of flux. The lamination does not cut across the lines of flux, so iron particles would not be attracted to the laminations.

Turn to page 2-67.

"No" is the correct answer. Iron particles would not be attracted to the lamination.

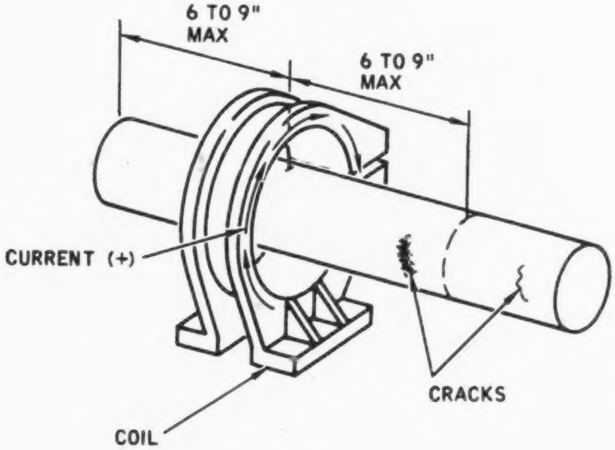


The laminations are oriented in the same direction as the lines of flux. Therefore, there would be no flux leakage to attract iron particles.

The effective length of the magnetic field in an article magnetized with a coil is 6 to 9 inches on either side of the coil. The 6 to 9 inch rule is a variable resulting from the differences in permeability of the various ferromagnetic materials. For example, the effective length of the field for soft iron which is highly permeable would probably be 9 inches. The effective length for hard steel which has low permeability might be 6 inches.

Turn to the next page.

Any cracks within the 6- to 9-inch range on either side of the coil will develop sufficient flux leakage to attract iron particles.



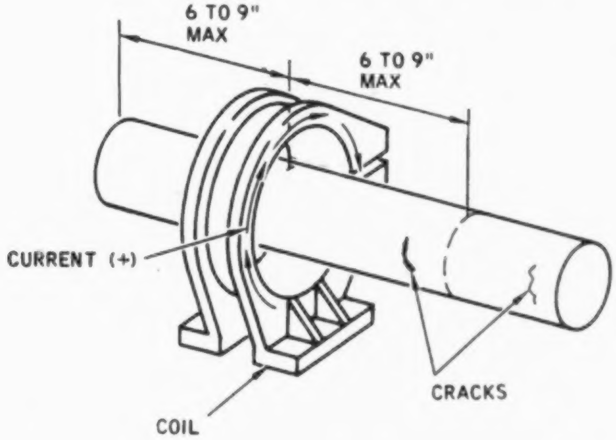
Cracks that are not within the 6- to 9-inch range will not have sufficient flux leakage. In other words, an article longer than 12 to 18 inches would require two coil shots.

How many coil shots would it take to adequately magnetize an article 20 inches long?

Two . . . . Page 2-69

One . . . . Page 2-70

Right. It would take two coil shots to adequately magnetize an article 20 inches long. Any article under 12 to 18 inches long would only require one coil shot.



In order to attract iron particles to the crack on the right, the article would have to be moved to the left so that the crack would be within 6 to 9 inches of the edge of the coil.

The 6- to 9-inch rule-of-thumb is based on the amount of current used and the permeability of the material being magnetized. Effective use of the rule must be based on experience with its application.

Turn to page 2-71.

From page 2-68

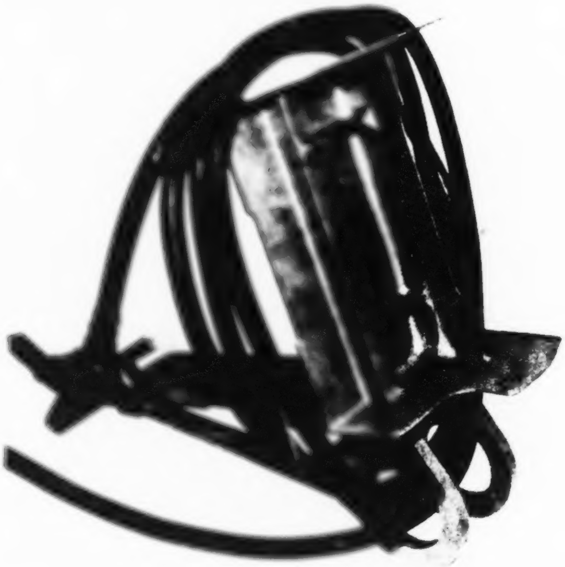
One coil shot would not adequately magnetize an article 20 inches long. Remember, the maximum effective distance of a coil shot is 18 inches with easily magnetized (highly permeable) material. Some kinds of material which have low permeability may require as little as 12 inches per shot. In any event, an article that is over 18 inches long will require two coil shots.

Turn to page 2-69.

From page 2-69

MAGNETIZATION BY CABLE

Sometimes test articles are too big to fit into the ordinary coil. When this happens, a copper cable can be used to form a coil for longitudinal magnetization of the article. Here is an example.



When the cable is wrapped around the object to be magnetized, electric current passing through the cable creates a longitudinal magnetic field.

The effective distance of the longitudinal magnetic field created by the cable is the same as the effective distance of a stationary coil. Which of the following is the correct effective distance of the magnetic field?

6 inches on both sides of cable .... Page 2-72

6 to 9 inches on both sides of cable .... Page 2-73

12 to 18 inches on both sides of cable .... Page 2-74

From page 2-71

Yes, the magnetic field is effective for 6 inches on either side of the coil, but, that is not all there is to it.

The permeability of the material is the deciding factor. For example, soft iron and iron with a low carbon content are highly permeable, and the effective distance of the longitudinal magnetic field may run as high as 9 inches on either side of the coil. On the other hand, with hard steel of high carbon content, the effective magnetic field may be as low as 6 inches.

Return to page 2-71 and try again.

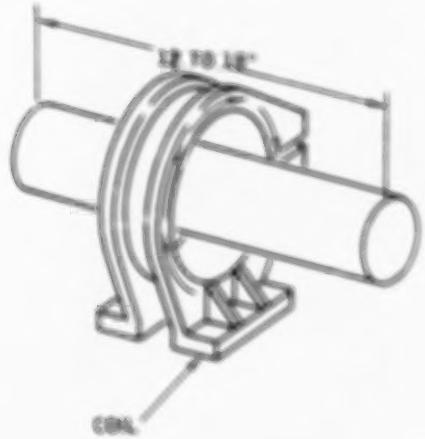
From page 2-71

Correct. The effective distance of the longitudinal magnetic field created by the cable coil is 6 to 9 inches on both sides of the cable.

Above is another example using a copper cable to create a longitudinal magnetic field in an article. In this case, the cable is connected to the heads for a source of electric current.

Turn to page 2-75.

No, "12 to 18 inches on both sides of the cable" is not the correct answer. You are confusing the total distance with the distance on both sides of the cable. In other words, the total effective distance of the longitudinal magnetic field within the coil is 12 to 18 inches.



Return to page 2-71 and try again.

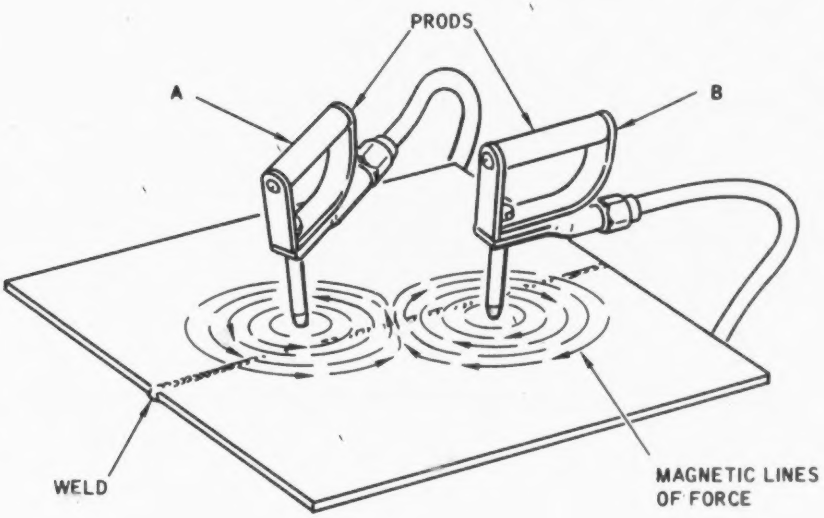
From page 2-73

USE OF PRODS

Prods are current-carrying conductors (round, copper bars) which are used to magnetize localized areas.

CAUTION

> The use of prods may be restricted for many applications due to the possibility of burns at the points of contact with the test article. The test operator should determine the acceptability of prod use before proceeding with the test.



Prods are connected by cable to the current source. When electric current flows through the prods, a circular magnetic field is created in the test object.

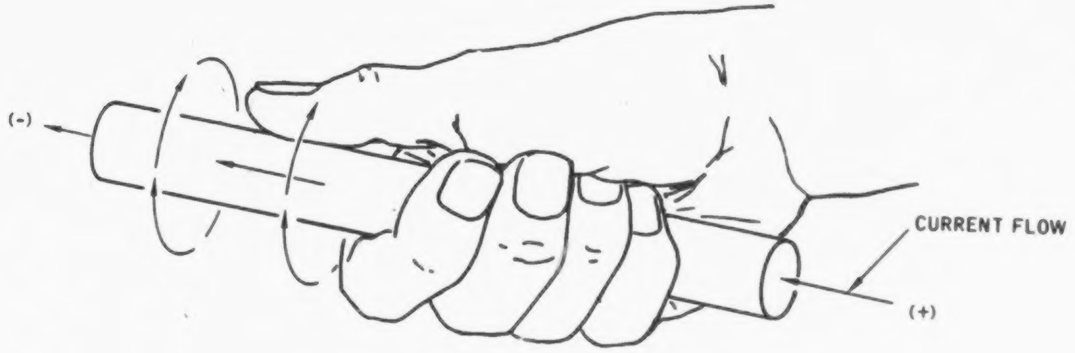
Determine the prod (A or B) through which electric current is entering. In other words, which prod is the positive (+) end of the electric circuit?

A .... Page 2-76

B .... Page 2-77

From page 2-75

You selected A. You are a little rusty on the right-hand rule, so let's review it just a little.



First, remember that electric current flows from the positive (+) end to the negative (-) end.

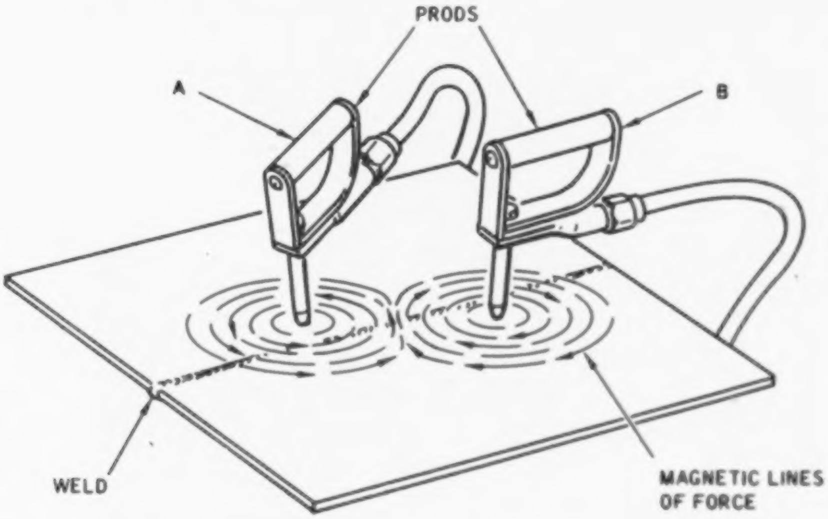
By placing the thumb in the direction of current flow, and wrapping the remaining fingers around the wire, the fingers will point in the direction of the lines of force, or flux.

With the prods, just imagine you are grasping the lower part (copper bar) with your right hand.

Return to page 2-75 and study the problem again.

From page 2-75

That's right. Electric current is entering prod B.



The electric current enters prod B and leaves through prod A. This causes a clockwise direction of the lines of flux around prod B, and a counterclockwise direction of the lines of flux around prod A. The counter-rotation of the two sets of lines of flux cause the flux density to be greatest between the prods.

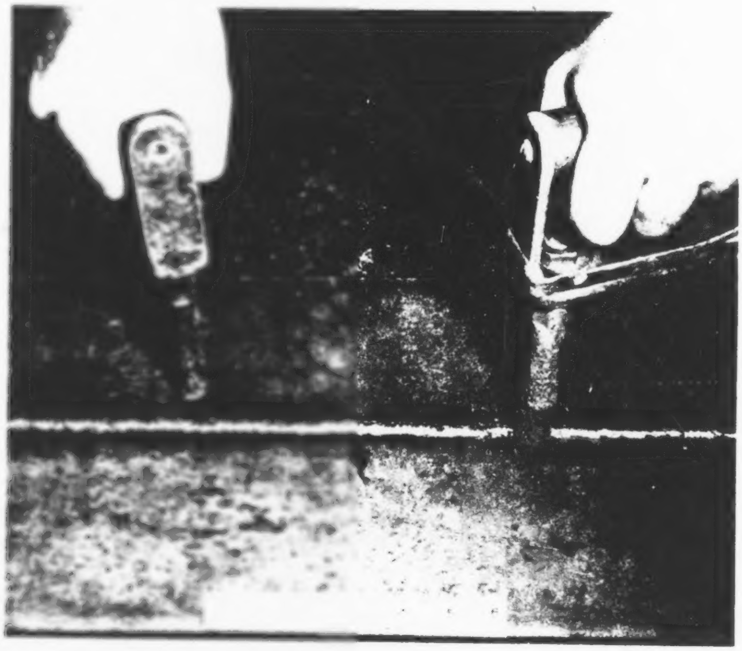
If a longitudinal shrink crack were located in the weld between the prods, would iron particles be attracted to the crack?

Yes.. Page 2-78

No... Page 2-79

From page 2-77

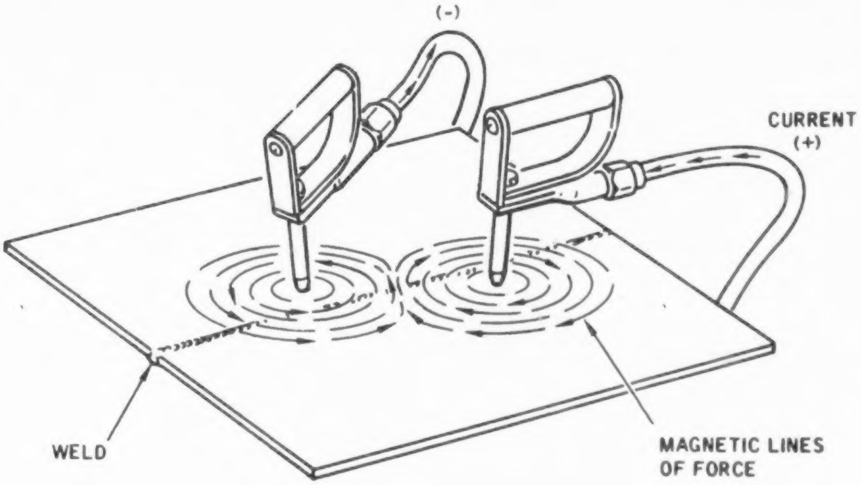
Yes, of course. A longitudinal shrink crack in the weld between the prods would attract iron particles. A longitudinal shrink crack would be nearly 90° to the lines of flux. This would cause flux leakage which would attract iron particles.



Prod magnetization is most effective when the prods are spaced 6 to 8 inches apart as in the above picture.

Turn to page 2-80.

You selected "No." Well let's take another look at this and see if you still feel that way.



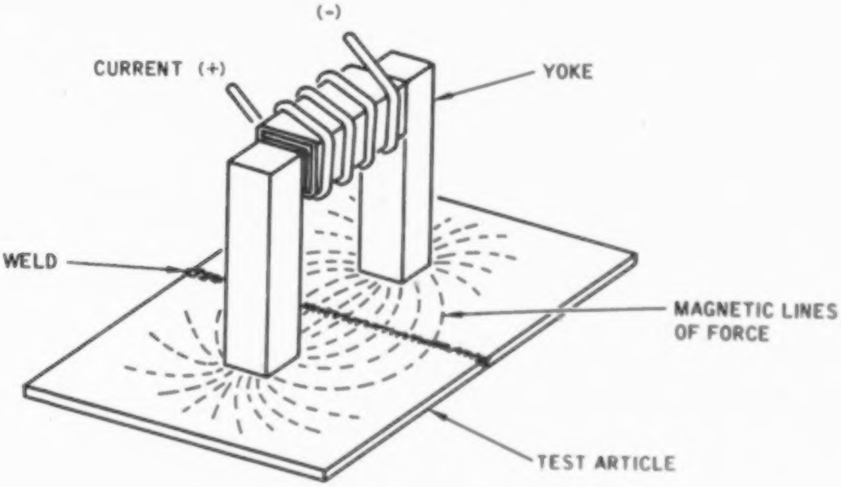
The rule that cracks which are between 45° to 90° with the lines of flux will cause flux leakage also applies to use of prods. In this case, the shrink crack in the weld is located between the prods. The lines of flux between the prods are crossing the weld between 45° and 90°. So iron particles would be attracted to the shrink crack.

Return to page 2-77 and study the problem again.

From page 2-78

USE OF A YOKE

A yoke is a U-shaped piece of metal with a coil wound around it to carry the magnetizing current. When the coil is energized, and an article is placed across the poles of the yoke, a longitudinal magnetic field will be set up in the test object.


(-)
CURRENT (+)
YOKE
WELD
MAGNETIC LINES OF FORCE
TEST ARTICLE

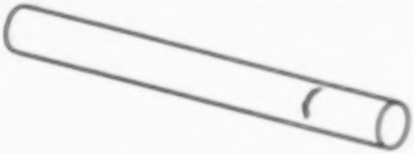
Turn to the next page.

From page 2-80

1. Review.

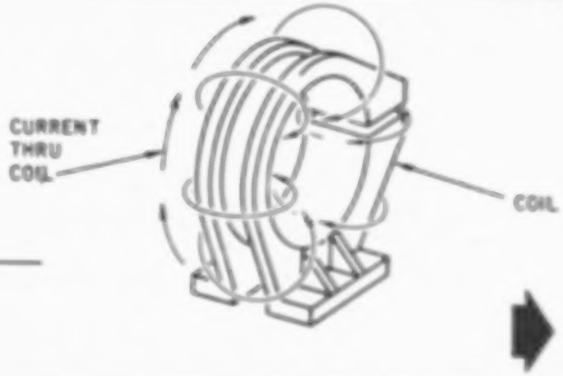
When an article is placed inside a coil through which electric current is passing, a lon______________field is set up in the article.

4. longitudinal



5. If we want iron particles to be attracted to this crack, we must magnetize the bar by passing current through a______________.

8. circular

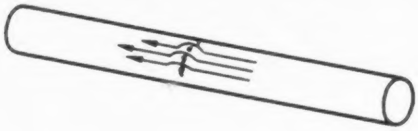


9. The flux density in a coil is______________ near the inside surface of the coil.

12. circular, longitudinal

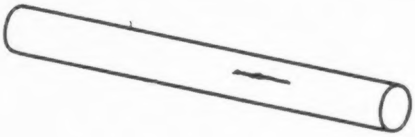
13. To be most effective, prods are held_______to_______inches apart.

1. longitudinal



2. A longitudinal field will cause__________ __________________at cracks which run crosswise to the lines of flux.

5. coil



6. If we want iron particles to be attracted to this crack, we must magnetize the bar by passing current through the____________.

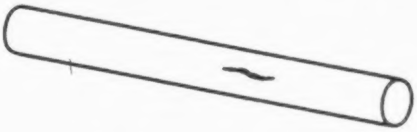
9. strongest

10. When an article is too big to fit an ordinary coil, we use a cable wrapped around the article to take the place of the ordinary coil. When electric current is passed through the cable, a________________ field is produced in the article.

13. 6 to 8

14. Turn to page 3-1.

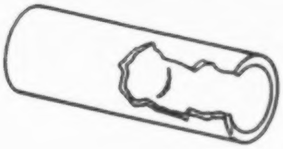
2. flux leakage



3. Here is a bar with a crack in it. We can establish either a circular field or a longitudinal field in this bar. Which field will cause flux leakage at the crack?

circular - longitudinal?

6. bar (article)

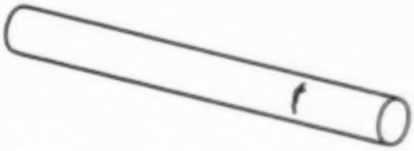


7. Here is a tube with a crack on the inside surface. If we want flux leakage at that crack, we must magnetize the tube with a________________________field.

10. longitudinal

11. The effective distance of the longitudinal magnetic field produced either by the looped cable or the ordinary coil is_______to_______inches on either side of the coil.

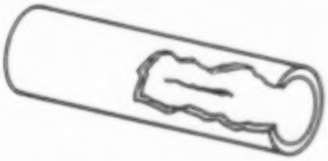
3. circular



4. Which type of field will cause flux leakage at this crack?
circular - longitudinal?

Return to page 2-81, frame 5.

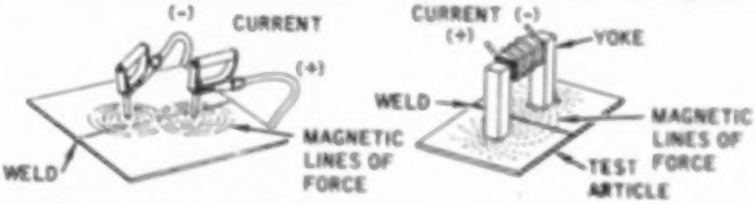
7. longitudinal



8. Here is a tube with a crack on the inside surface. If we want flux leakage at this crack, we must magnetize the tube with a ________________ field.

Return to page 2-81, frame 9.

11. 6 to 9

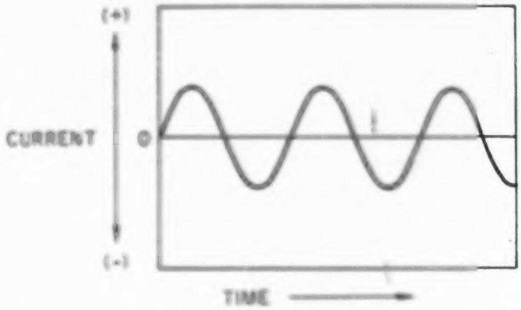

(-)
CURRENT
(+)
WELD
MAGNETIC LINES OF FORCE
CURRENT (-)
(+)
YOKE
WELD
MAGNETIC LINES OF FORCE
TEST ARTICLE

12. The magnetic field set up by a pair of prods is essentially________________, while the magnetic field set up by a yoke is essentially________________.

Return to page 2-81, frame 13.

Alternating Current. Alternating current (ac) is the most convenient source of electrical current since it is provided by nearly all utility services. For this reason, it is the most widely used power source for conducting magnetic particle testing.

The commonly used single phase ac requires two conductors (wires) and reverses direction at the rate of 60 cycles per second as shown by this ac sine curve.



Alternating current at line voltages can be stepped up or down with relative ease and economy by the use of transformers. Therefore, ac can be readily converted to the low voltages used in magnetic particle testing.

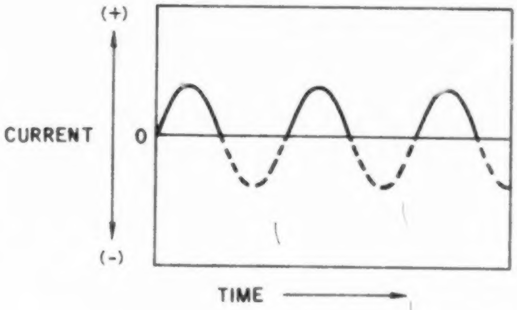
Alternating current has relatively little penetrating ability. Therefore, the magnetic field induced by ac current is concentrated near the surface of the article being magnetized. For this reason, ac magnetization provides the best detection of surface discontinuities. It is not effective in detecting sub-surface discontinuities.

Since ac is continuously reversing direction at the rate of 60 cycles per second, the constantly reversing magnetic field has a tendency to agitate or make the iron particles more mobile. This causes the iron particles to be more responsive to flux leakage fields.

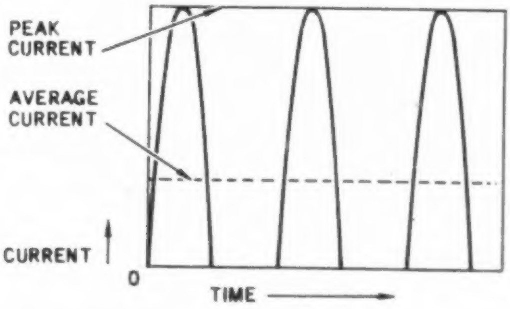
Turn to the next page.

From page 3-1

Direct Current. When single phase ac is rectified, the resulting current is known as halfwave alternating current (HWAC). In effect, this is a pulsating dc current and is often called halfwave direct current (HWDC). This simply means that the reverse polarity or negative portion of the ac sine curve is eliminated.



The halfwave direct current consists of individual pulses of direct current with time intervals in which no current is flowing.



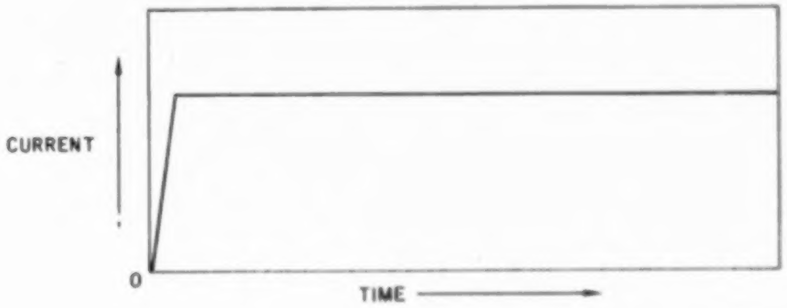
Each pulse lasts for one-half cycle, and the peak current is the same as the alternating current which is being rectified. The average current is considerably less than the peak current.

Turn to the next page.

From page 3-2

Although half wave rectified, single phase ac is a type of direct current, it is always identified as half wave direct current or HWDC. This allows differentiation between it and true dc which is a continuous flow of current in one direction.

A common source of dc is the ordinary battery.



Notice that the current flow is flat in comparison to the strong pulse from HWDC.

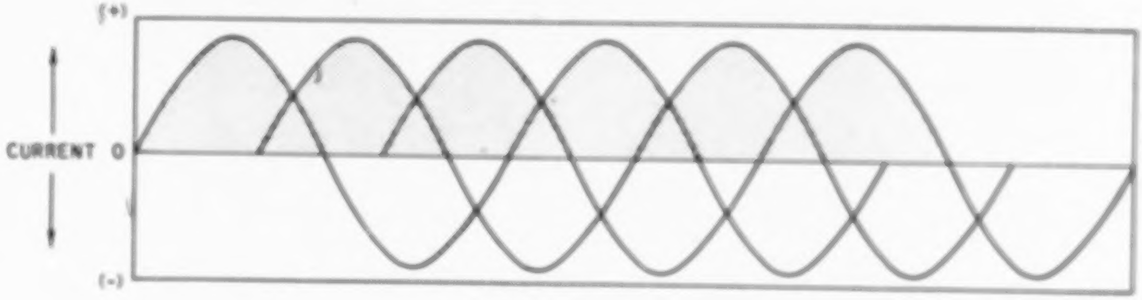
At one time, batteries were commonly used to provide dc for magnetic particle testing. However, batteries presented many obvious problems and have now been largely replaced by other sources of dc.

Turn to the next page.

From page 3-3

A clue to these other sources of dc was given on the first page of our discussion of magnetizing currents. We said that ac is "the most widely used power source for conducting magnetic particle testing."

You have seen how single phase ac can be rectified to give a pulsing type of dc. Now let's see what we can do with 3 phase ac.



If this current is half wave rectified, we have a pulsing dc, but the shaded portion now bears a stronger resemblance to battery dc.

What would happen if the 3 phase current was given full wave rectification. In other words, what if the negative portion of each curve was switched in such a way that it flowed in the positive direction along with the positive section of the curve?

It would make the positive portion of each curve higher .... Page 3-5
It would smooth out the ripple even more .... Page 3-6

From page 3-4

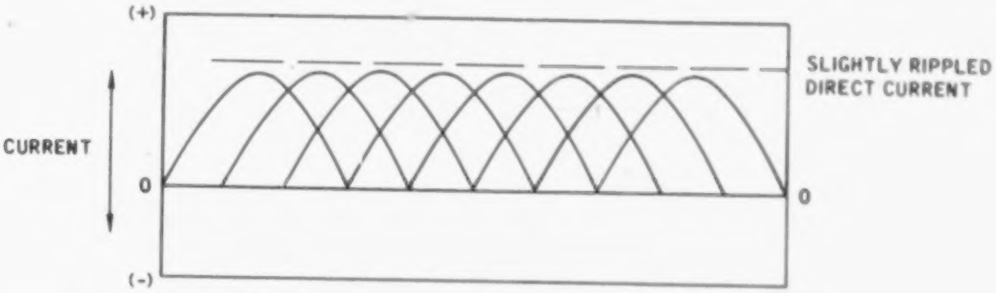
Sorry. Notice that the negative peaks are located vertically between the positive peaks.

If the negative current flow were reversed, the number of peaks would double — each valley between a peak would be filled with another peak.

Turn to page 3-6.

From page 3-4

Very good. Full wave rectification reverses the direction of the negative portion of the curve and all current flows in the same direction. We would have double the number of peaks on the positive curve.



For all practical purposes, this current is the same as battery dc. It has an almost constant value with only a slight ripple.

We have stated that ac has little penetrating ability — it travels on the surface of a conductor. For that reason, the magnetic field established by ac is very close to the surface. Dc is much more penetrating. It travels within the conductor as well as on the surface. For that reason, the magnetic fields it induces are deeper.

If you were looking for a crack beneath the surface of a specimen, which type of current would be best to use?

ac . . . . Page 3-7
dc . . . . Page 3-8

From page 3-6

Nope. You weren't paying attention. Alternating current will establish surface magnetic fields — magnetic flux would not penetrate very deeply into the specimen.

Alternating current is fine for detecting surface cracks where the flux leakage would be high. But subsurface flux density is very weak at best and would not be adequate for the detection of subsurface cracks.

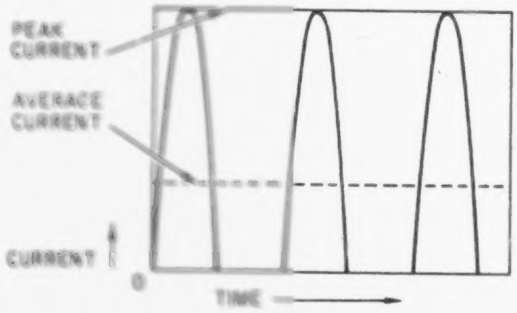
Turn to page 3-8.

From page 3-6

Absolutely. The flux density inside a specimen is much greater using dc than with ac. Dc or HWDC should always be used for subsurface investigations.

We've now established the fact that ac can be used to detect surface discontinuities only. Also, dc must be used to detect subsurface discontinuities although it will also detect surface discontinuities. We have talked about 2 kinds of dc; half wave rectified which we have labeled "HWDC," and full wave, 3 phase rectified which we call "dc."

Now let's examine the relative advantages of HWDC and dc. Here is our diagram of HWDC again.



The flux density in a specimen is determined by the peak current of the HWDC.

The power requirements and heating effects are determined by the average current.

Now, can you see a possible advantage in using HWDC?

Turn to page 3-9.

From page 3-8

That's right. A high flux density can be generated using a minimum of current. The ratio is roughly 3 to 1. For example, if an average current of 400 amps,is used, the peak current will be about 1200 amps. And the flux density will reflect this peak current.

Another advantage of HWDC is the strong pulsing action of the magnetic flux. This serves to agitate dry magnetic powders (particles) and makes them more responsive to leakage fields.

For these reasons, HWDC is often used in portable, dry method equipment. It provides deep penetration and good dry powder agitation. The combination is quite sensitive in the location of subsurface defects.

If only surface discontinuities are being sought, which type of current would provide the strongest leakage fields at the surface of a specimen?

HWDC . . . . Page 3-10

Ac . . . . Page 3-11

From page 3-9

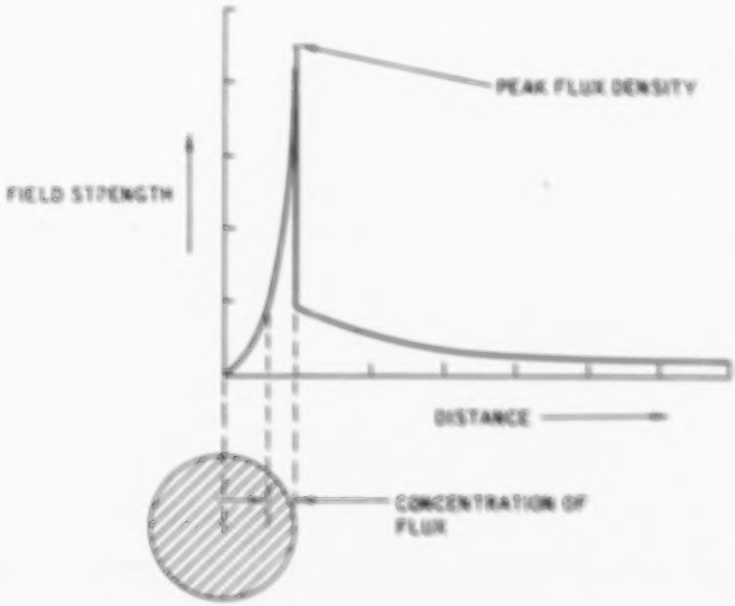
You think HWDC would provide the strongest leakage field at the surface of an article. It is true that HWDC is used to locate both surface and subsurface discontinuities but since it tends to distribute itself throughout the cross section of the article, the flux density at the surface is not as great as with ac.

Turn to page 3-11.

Page 3-9

Absolutely. 60 cycle ac provides the strongest leakage fields for surface discontinuities such as cracks or seams. Alternating current tends to flow near the surface of a conductor. Therefore, flux density is greatest at the surface when using ac.

Consider this diagram showing the magnetic field distribution when alternating current flows through a solid magnetic conductor such as a round steel bar.



Starting at the center of the article, flux density is zero. As you can see, the greatest flux density is concentrated very near the surface of the article. It is for this reason that 60 cycle ac is widely used to detect surface discontinuities.

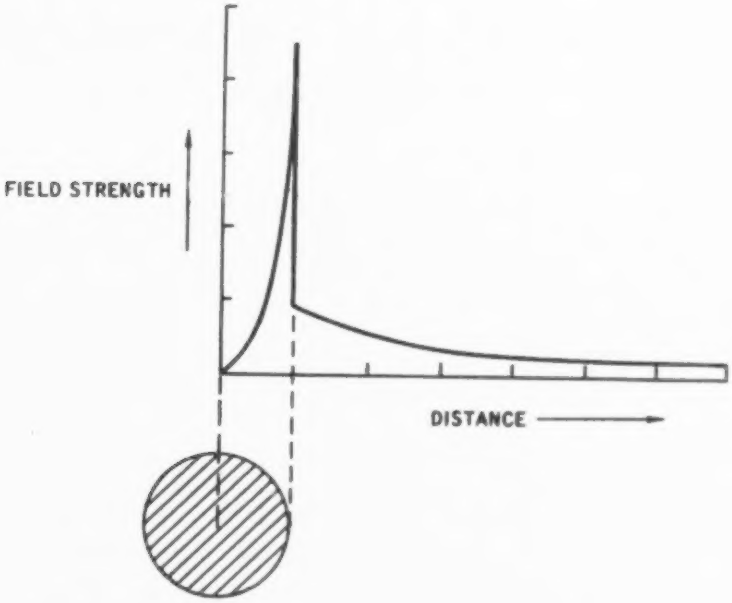
If you were to circularly magnetize a hollow steel bar by passing 60 cycle ac through its length, where do you think the current would tend to flow through the article?

Near the inside surface (ID) of the article .... Page 3-12

Near the outside surface (OD) of the article .... Page 3-13

From page 3-11

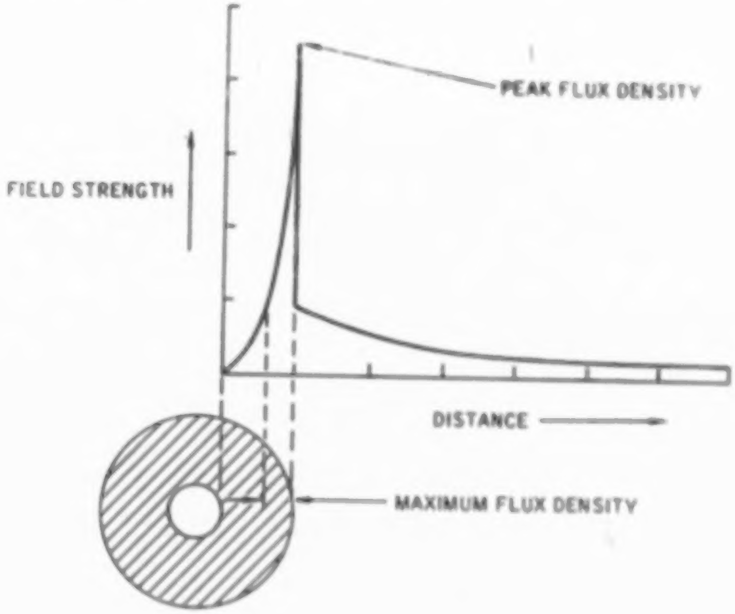
You think ac would tend to flow near the inside surface of a hollow steel bar. No, 60 cycle ac always tends to flow near the outside surface of any conductor including the hollow steel bar.



In the case of the solid piece of steel, the electric current is zero at the center. The largest portion of the current then moves rapidly toward the surface as shown by the curved portion pointed out by the arrow in the above illustration. This same phenomenon would occur in a hollow steel bar also.

Turn to page 3-13.

Yes sir. 60 cycle ac will always tend to flow near the outside surface on any conductor including the hollow steel bar. It is obvious that if the electric current density is concentrated in the outer layer of the conductor, the flux density will be correspondingly greater in that area. Here is a diagram showing the distribution of the magnetic field in the hollow steel bar through which ac is flowing.



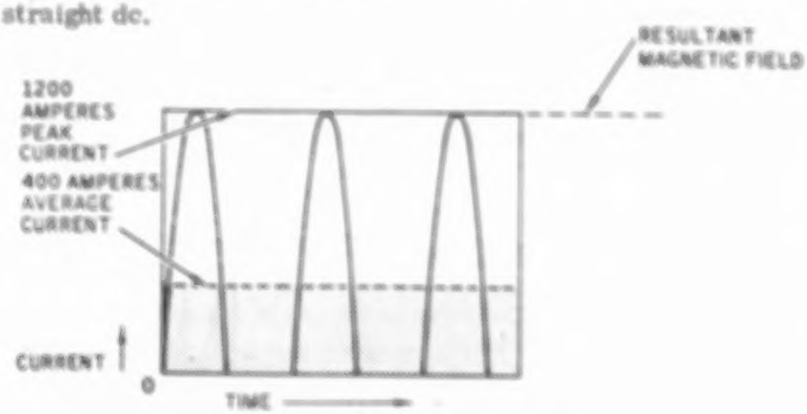
Here again, the magnetic field is zero at the inside surface (ID) of the article and the flux density is concentrated very near the outside surface of the article. For this reason, 60 cycle ac is not used to locate subsurface discontinuities.

Assuming the same current (amperage), which of the following types of current provides the best penetration qualities?

Halfwave dc . . . . Page 3-14
Dc . . . . Page 3-15

From page 3-13

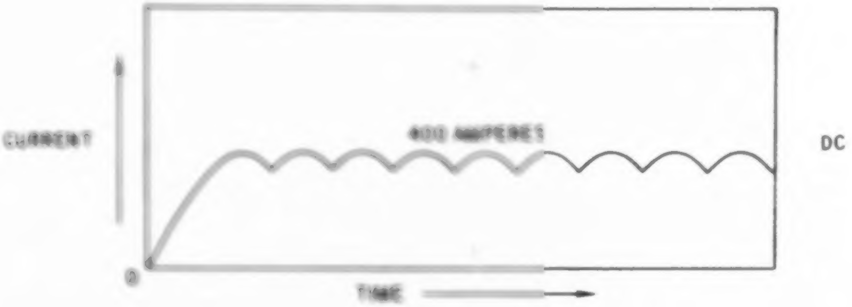
Right. Halfwave dc provides the best penetration qualities for locating deep subsurface discontinuities. For a given amperage, HWDC will produce a stronger magnetic field than that provided by straight dc.

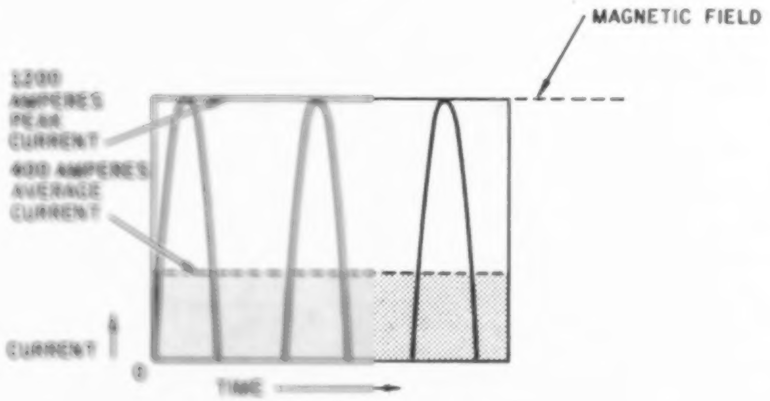


With either ac or dc, the magnetic field varies directly with the amount of magnetizing current used. In other words, when current is increased the magnetic field strength increases. It is also true that the distribution of the electric current determines the distribution of magnetic flux. With this in mind, let us take a look at the distribution of the magnetic field in a solid steel article through which dc is flowing.

Turn to page 3-16.

No. For a given amperage, dc does not have the best penetration qualities. Let's compare the three types of dc remembering that the magnetizing current is equal for all three types.



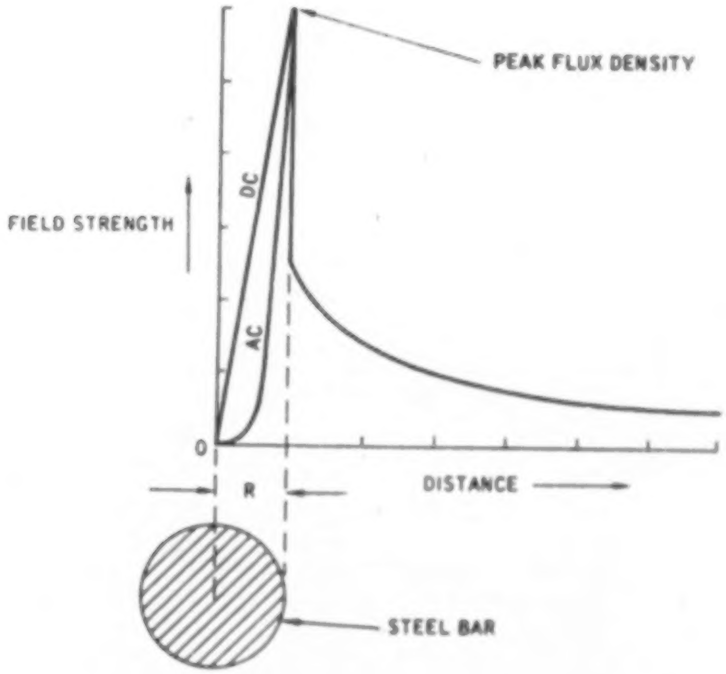


Flux density is determined by the peak current used. With straight dc, the peak current is 400 amps and the flux density reflects this peak. HWDC of 400 amps average value has a peak current of approximately 1200 amps. The resultant flux density will be much higher than with dc.

Turn to page 3-14.

From page 3-14

Direct current has better penetration qualities as shown by the ac and dc curves here.



With dc, flux density increases evenly on a straight line from zero at the center of the article to the surface. The ac line, however, veers sharply toward the outside before flux density increases appreciably. Since flux density also represents current density, the ac and dc lines above also represent current distribution in the article.

We can say that dc creates:

A stronger internal magnetic field than does ac . . . . Page 3-17

A stronger surface magnetic field than does ac . . . . Page 3-18

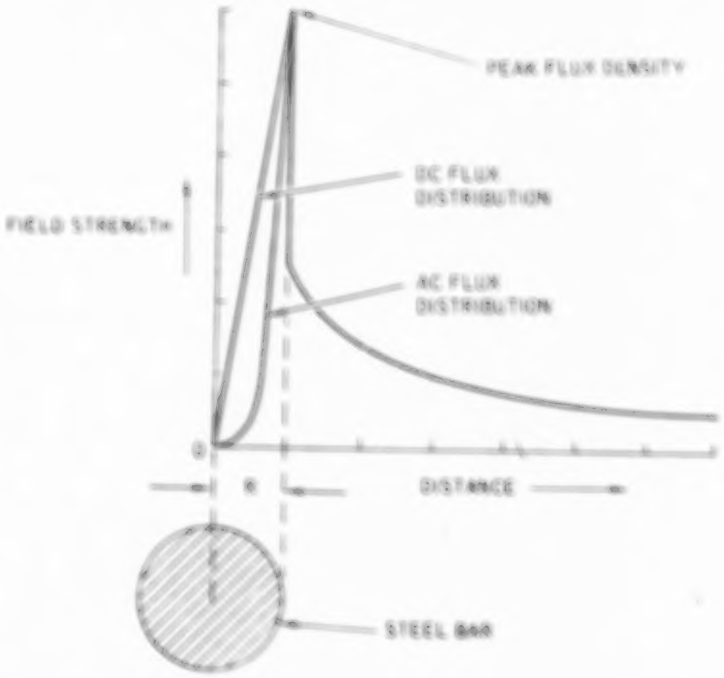
From page 3-16

Right. Direct current creates a stronger internal magnetic field than does ac. Direct current, and particularly halfwave dc, is ideal for detecting subsurface discontinuities.

The comparative differences in sensitivity between alternating current and direct current depends largely on the type of magnetic particles used and the method of testing. These will be discussed in some detail later.

Turn to page 3-19.

No, dc does not create a stronger surface magnetic field. You may have been confused by the diagram. Let's look at it once more.



The arrow on the left is pointing to the direct current (dc) magnetic field distribution in the article. The arrow on the right is pointing to the alternating current (ac) magnetic field distribution in the article. The ac line shows a sharp outward turn which indicates that the flux density is concentrated near the outer surface of the article. In contrast, the dc line shows an even progression to the peak flux density point. This means that the flux density is progressively increasing at a constant rate. Therefore, it indicates that dc creates a stronger internal magnetic field than does ac.

Turn to page 3-17.

From page 3-17

REVIEW

1. Common alternating current (ac) reverses polarity at the rate of ______cycles per second.

➡

5. direct

6. When 3-phase, alternating current is rectified, for practical purposes it can be considered to be straight_________ _____________.

➡

10. magnetic

11. When amperage is the same, HWDC provides the strongest subsurface magnetic field and is the best type of current for locating ______________ discontinuities.

➡

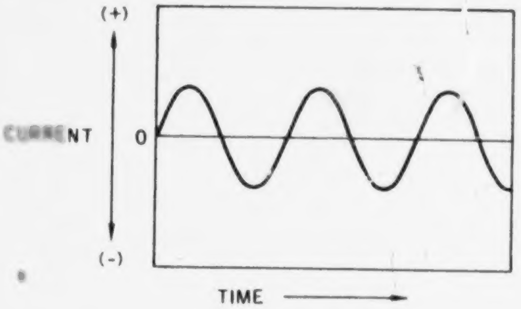
15. surface

16. Because ac flux density is concentrated near the surface, it is ineffective for locating_________________discontinuities.

➡

1. 60

2. The alternating nature of ac is shown by this ac sine ____________.



➡

---

6. direct current

7. Batteries are no longer in common use as a source of ___________ ___________.

➡

---

11. subsurface

12. The continuous cycle pulsing of HWDC tends to provide a vibratory movement or mobility to dry magnetic particles which aids in their attraction to weak ________________ fields.

➡

---

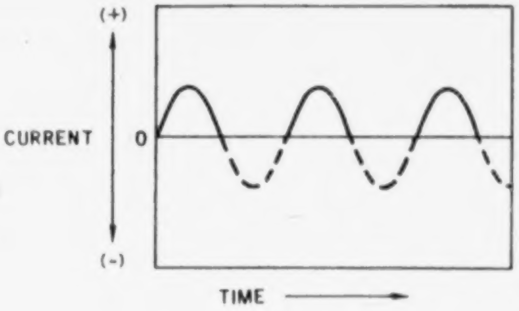
16. subsurface

17. Because of the continuous cyclic reversing of polarity, 60 cycle ac also causes a vibratory movement of magnetic particles which aids in their attraction to ___________ ______________.

➡

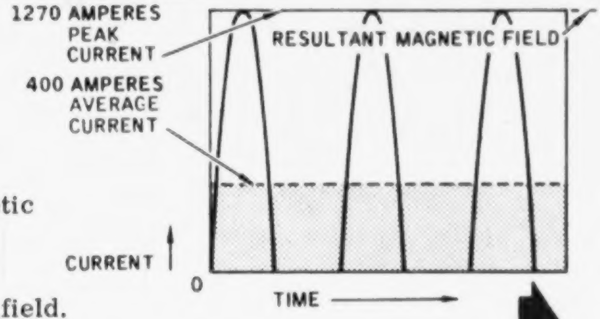
2. curve

3. When single phase ac is rectified, the negative polarity portion of the sine curve is el_______________.



7. direct current

8. When straight HWDC is used for magnetic particle testing, the peak current determines the resultant_____________field.



12. leakage

13. In contrast to direct current, 60 cycle alternating current flows near the__________________of an article.

17. leakage fields
(flux leakage)

18. Direct current has better penetrating qualities than __________________current.

3. eliminated
(removed)

4. When the negative cycle of the ac sine curve is eliminated, the resulting current is often called half-wave___________current (HWDC).

8. magnetic

9. Given the same magnetizing amperages for the two types of dc, HWDC provides the greatest___________________qualities.

13. surface

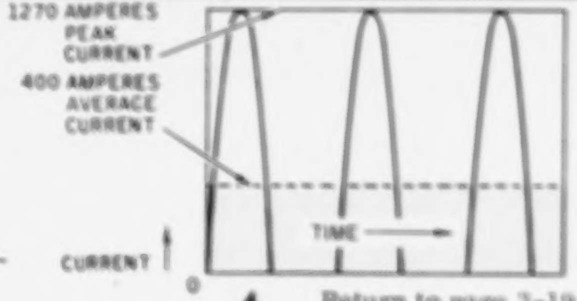
14. Because ac tends to flow near the surface of an article, ______________ __________is greatest near the surface of the article.

18. alternating

19. Turn to page 3-24.

4. direct

5. Half-wave dc consists of individual pulses of__________ current.



Return to page 3-19, frame 6.

9. penetration

10. Since direct current is distributed more evenly over the cross section of an article being magnetized, dc provides a stronger subsurface__________ __________field than does ac.

Return to page 3-19, frame 11.

14. flux density

15. Because ac flux density is greatest near the surface of an article, it is the most effective for detecting __________discontinuities.

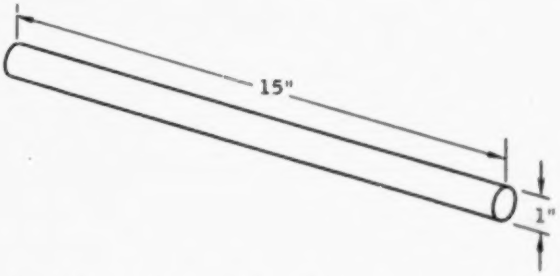
Return to page 3-19, frame 16.

From page 3-22

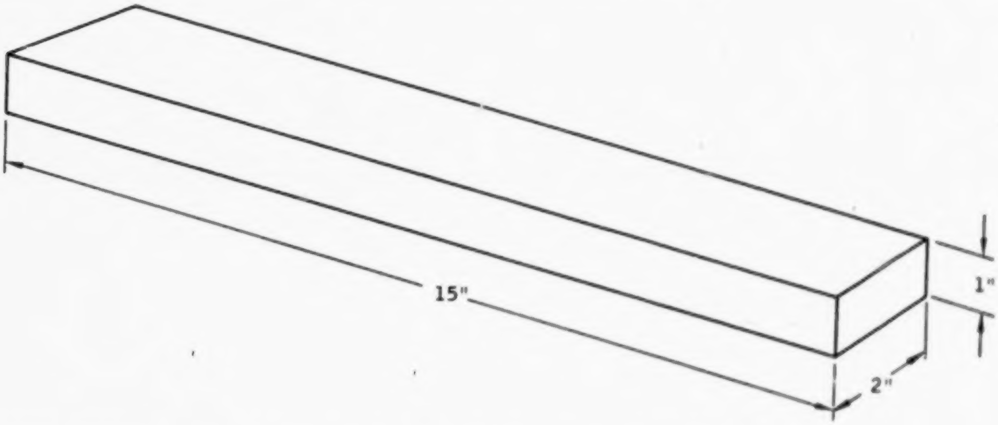
CURRENT REQUIREMENTS (CIRCULAR MAGNETIZATION)

The amount of electric current used will vary with the shape of the article and with the permeability of the material. For example, too much current may burn the article or may cause very heavy accumulations of iron particles. Too little current may not be adequate to provide sufficient flux leakage to attract iron particles. Since there are so many variables involved in determining current requirements for individual articles, only general rules can be provided. For our purposes here, let us use the following rule in determining the current needed for circular magnetization between the heads and with the central conductor.

USE 600 to 800 AMPERES PER INCH OF ARTICLE THICKNESS OR DIAMETER



This round bar is 1" in diameter. In applying the rule, you would use 600 to 800 amperes for circular magnetization. Here is another example.



How many amperes would you use to circularly magnetize this bar?

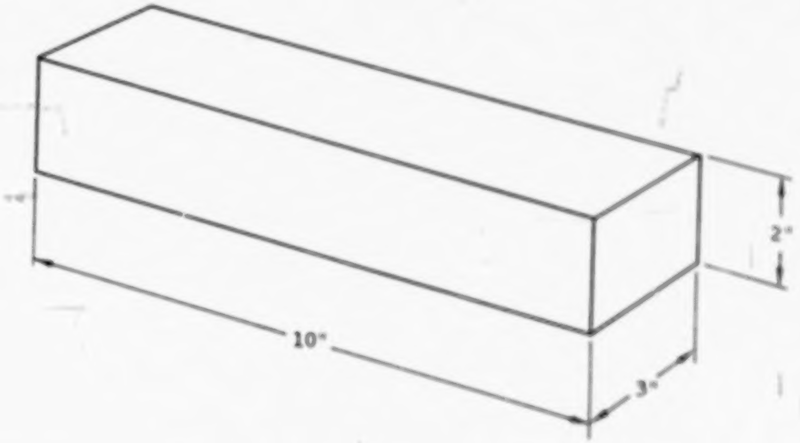
600 to 800 amperes . . . . Page 3-25

1200 to 1600 amperes . . . . Page 3-26

Right. The bar was only one inch thick so you would use an ampere range of 600 to 800 amperes to circularly magnetize that bar. Here is the rule again.

USE 600 to 800 AMPERES PER INCH OF ARTICLE THICKNESS OR DIAMETER

To use this rule on articles of greater thickness, we just multiply 600 by the number of inches of article thickness and 800 by the number of inches of article thickness. For example, here we have an article that is 2" thick.

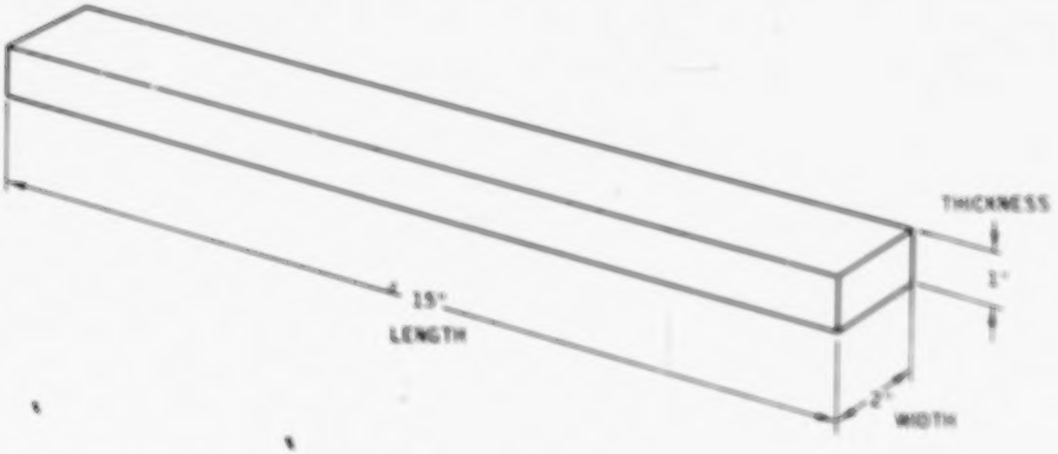


What ampere range would be needed to circularly magnetize this bar?

600 to 800 amperes	Page 3-27
1200 to 1600 amperes	Page 3-28
1800 to 2400 amperes	Page 3-29

You selected — 1200 to 1600 amperes. You have mixed thickness of the article with the width of the article.

Thickness of an article is always its smallest dimension. For example, our test article was 1 inch thick, 2 inches wide, and 15 inches long.



So, you can see that using the rule of 600 to 800 amperes per inch of article thickness would allow a range of 600 to 800 amperes for the above article.

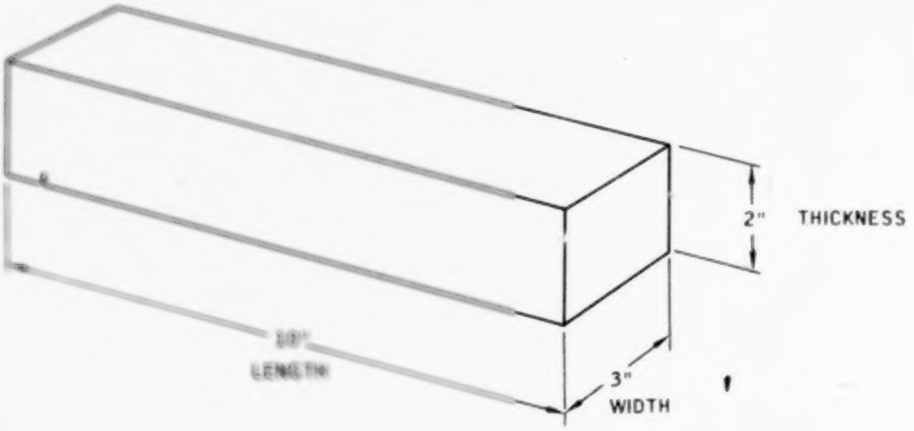
Turn to page 3-25.

From page 3-25

You chose 600 to 800 amperes. But the article is 2 inches thick, not 1 inch. Look at the rule.

USE 600 to 800 AMPERES PER INCH OF ARTICLE THICKNESS OR DIAMETER

Here is the article again.



Determine amperes required as follows:

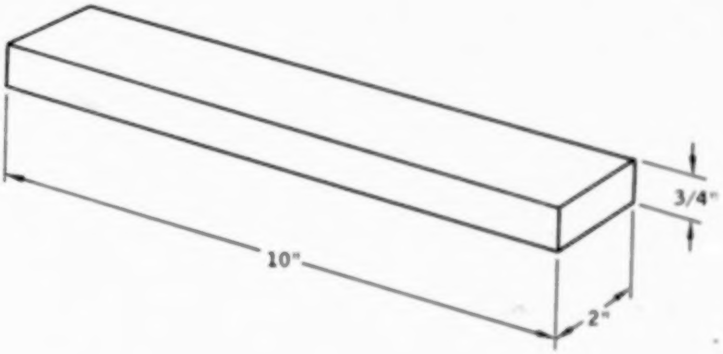
2 x 600 = 1200   2 x 800 = 1600

Amperes required = 1200 to 1600

Return to page 3-25 and select the correct answer.

Exactly. It would take 1200 to 1600 amperes to circularly magnetize the bar. You simply multiplied; 600 x 2 = 1200 and 800 x 2 = 1600.

Now, if the article happens to have a thickness less than one inch, we would use only a part of the 600 to 800 amperes. For example, here we have an article that is 3/4 of an inch thick.



For this article, we would use only 3/4 of 600 to 800 amperes.

3/4 x 600 = 450 and 3/4 x 800 = 600

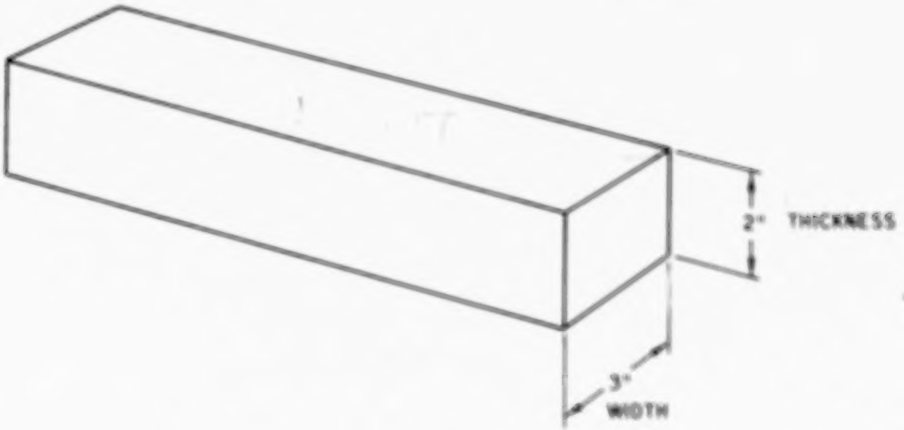
From this you can see that we would use between 450 and 600 amperes to circularly magnetize the above article.

Now, suppose we have an article that is only 1/2 inch thick. What would the amperage range be for circularly magnetizing this article?

450 to 600 ampere . . . . Page 3-30
600 to 800 ampere . . . . Page 3-31
300 to 400 ampere . . . . Page 3-32

From page 3-25

Ooooops! The article is 2 inches thick not 3 inches.


2"
THICKNESS
3"
WIDTH

Return to page 3-25 and figure it out again.

From page 3-28

Your answer is correct only if the article is 3/4 of an inch thick. Since our test article is only 1/2 inch thick, we multiply like this:

1/2 x 600 = 300 1/2 x 800 = 400

Amperes = 300 to 400

Turn to page 3-32.

From page 3-28

You selected — 600 to 800 amperes. That would be correct if the article was 1 inch thick. Since our test article is only 1/2 inch thick, it requires only 1/2 as much current.

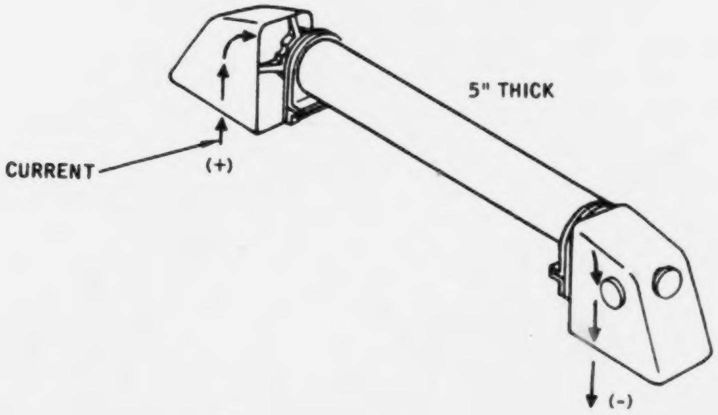
Return to page 3-28 and try again.

From page 3-28

Very good. You would use between 300 and 400 amperes to circularly magnetize that 1/2" article. Here is the rule once again.

USE 600 to 800 AMPERES PER INCH OF ARTICLE THICKNESS OR DIAMETER

Here is a 5" thick, round, steel bar already in the machine.



In the space below, compute the amperage range required to circularly magnetize this 5-inch thick, steel bar.

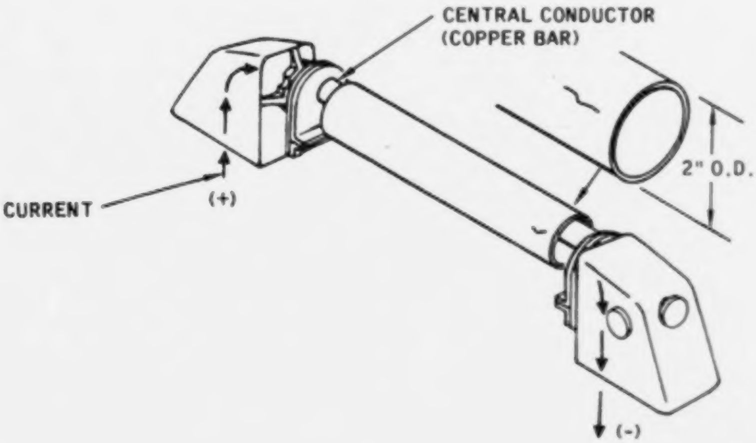
When you have solved the above problem, turn to the next page.

Your answer should be:

600 x 5 = 3000 and 800 x 5 = 4000

The solution is to use between 3000 and 4000 amperes on the 5-inch thick article.

The rule of using 600 to 800 amperes per inch of article thickness also applies to circular magnetization with a central conductor. In this case we are dealing with hollow articles, so the article thickness is taken from the outside diameter (OD) of the article.



The hollow tube has an outside diameter of 2". What would be the correct ampere range for this article?

600 to 800 amperes . . . . Page 3-34

1200 to 1600 amperes . . . . Page 3-35

From page 3-33

Your answer would be O. K. for a tube with a 1-inch outside diameter. Our tube has an outside diameter of 2 inches. You should have multiplied as follows:

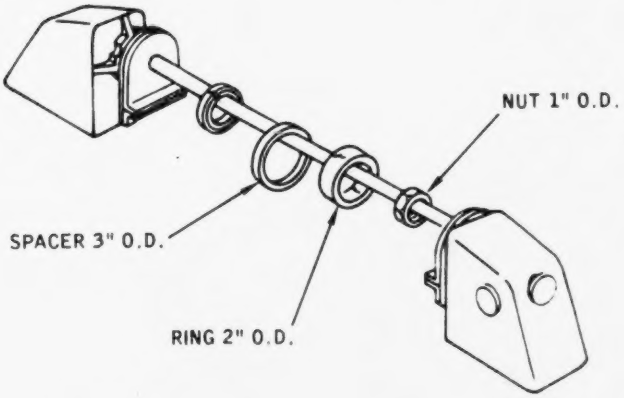
600 x 2 = 1200   800 x 2 = 1600

The ampere range for this article is 1200 to 1600 amperes.

Turn to page 3-35.

Right. The correct range for that 2" hollow article would be 1200 to 1600 amperes.

Here are some more examples:



In the space below, figure out the correct ampere range for each of the above three articles (nut, ring, and spacer).

When you have solved the above problems turn to the next page.

From page 3-35

Answers:

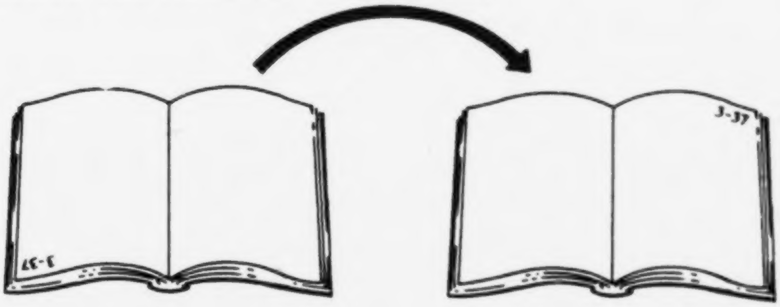
Spacer — 1800 to 2400 amperes

Ring — 1200 to 1600 amperes

Nut — 600 to 800 amperes

Now you are ready to start back through the book and read those upside-down pages.

TURN OR ROTATE THE BOOK 180° — LIKE THIS.



READ PAGE 3-37 AND CONTINUE AS BEFORE.

From page 3-36

CURRENT REQUIREMENTS (LONGITUDINAL MAGNETIZATION)

The amount of current needed for longitudinal magnetization with a coil is controlled by the following formula:

$$\frac{45,000}{\text{L/D Ratio}} = \text{Ampere-turns}$$

where: L = length of the article

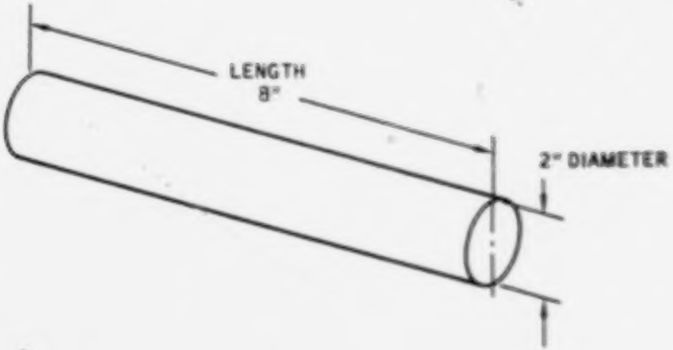
D = diameter or thickness of the article

The figure of 45,000 is a constant that remains the same for all computations.

L/D is the length-to-diameter, or thickness ratio, of the article. It may be expressed: length over diameter equals the L/D ratio

$$\frac{\text{length}}{\text{diameter}} = \text{L/D ratio}$$

In other words, the length of an article divided by the diameter will give the L/D ratio. For example:



$$\frac{\text{length}}{\text{diameter}} = \frac{8}{2} = 4$$

The length of the article, 8 inches, divided by the diameter, 2 inches, equals 4 which is the L/D ratio.

Turn to the next page.

Here is the formula again.

$$\frac{45,000}{\text{L/D Ratio}} = \text{Ampere-turns}$$

The L/D ratio of an article is determined by dividing the length of an article by the diameter of the article. In the space below, figure the L/D ratios for the following articles. Enter the figures in the L/D ratio column.

ARTICLE LENGTH (INCHES)	ARTICLE DIAMETER (INCHES)	L/D RATIO
9	3	
10	5	
14	1	
12	2	
18	1 1/2	

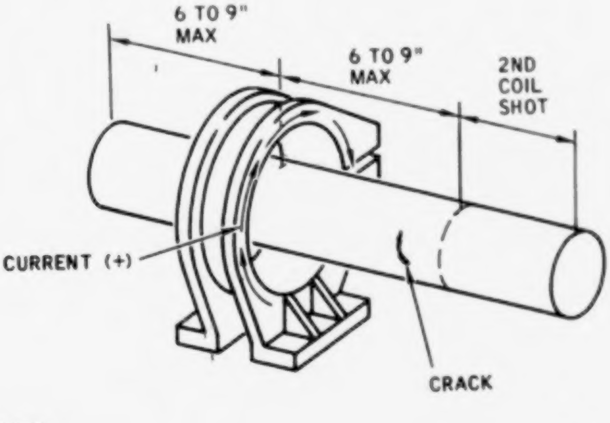
When you have computed the above L/D ratios, turn to the next page and check your answers.

From page 3-38

Here are the correct answers

ARTICLE LENGTH (INCHES)	ARTICLE DIAMETER (INCHES)	L/D RATIO
9	3	3
10	5	2
14	1	14
12	2	6
18	1 1/2	12

Notice that the above computations are based on articles that have a length no greater than 18 inches. As mentioned earlier, the effective length of a longitudinal magnetic field is 6 to 9 inches on either side of a coil. An article with a length greater than 18 inches will require two or more coil shots.

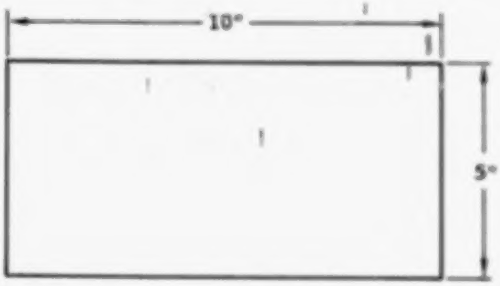


Turn to the next page.

Now that we have reduced the L/D ratio to a number, we can continue with the formula to determine the current required for longitudinal (coil) magnetization. Here is the formula again.

$$\frac{45,000}{\text{L/D Ratio}} = \text{Ampere-turns}$$

Let's work with an article 10 inches long with a diameter, or thickness, of 5 inches.



The L/D ratio is 2. $\frac{\text{Length}}{\text{Diameter}} = \frac{10}{5} = 2$

The L/D ratio of 2 is used in the formula in place of the L/D symbols.

$$\frac{45,000}{2} = \text{Ampere-turns}$$

To determine the ampere-turns, we simply divide 45,000 by the L/D ratio of 2. Determine the ampere-turns in our formula now.

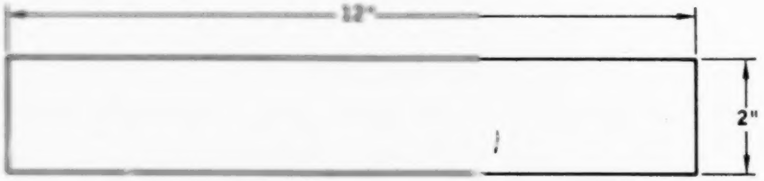
$$\frac{45,000}{2} =$$

Turn to the next page and check your answer.

Your answer should be:

$$\frac{45,000}{2} = 22,500 \text{ ampere-turns}$$

Very good. Let's try another example.



Using the formula, determine the ampere-turns for the above article.

$$\frac{45,000}{\text{L/D Ratio}} = \text{Ampere-turns}$$

In the space below, compute the answer to the above problem.

When you have computed the problem, turn to the next page and check your answer.

Your answer should be computed as follows:

$$\frac{L}{D} = \frac{12}{2} = 6$$

$$\frac{45,000}{6} = 7,500 \text{ ampere-turns}$$

If your answer is not correct, return to the previous page and recheck your figures.

The next and last step in computing current requirements for longitudinal magnetization is to reduce the number of ampere-turns to a figure that can be used. We do this by dividing the number of ampere-turns by the number of turns in the coil. Most coils have from 3 to 5 turns in them. Let's assume that our coil has 5 turns. Using the figure from the example above let's compute the magnetizing current.

$$\frac{45,000}{6} = 7,500 \text{ ampere-turns}$$

If the coil has 5 turns, then

$$\text{magnetizing current} = \frac{7,500}{5} = 1500 \text{ amperes}$$

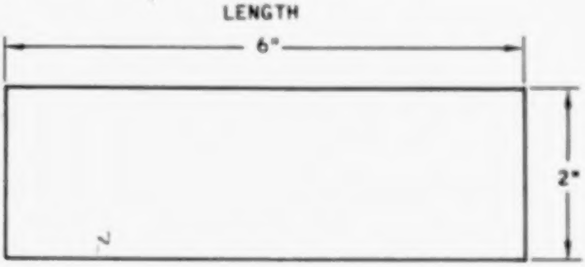
What would be the magnetizing current if our coil had only 3 turns? Compute the answer below.

Turn to the next page to check your answer.

Your answer should be as follows:

$$\text{magnetizing current} = \frac{7,500}{3} = 2500 \text{ amperes}$$

Compute the magnetizing current needed for this article.



Formula:

$$\frac{45,000}{\text{L/D Ratio}} = \text{Ampere-turns}$$

Using a 5 turn coil.

5 TURN COIL

Turn to the next page to check your answer.

Your answer should be computed as follows:

$$\frac{L}{D} = \frac{6}{2} = 3$$

$$\frac{45,000}{3} = 15,000 \text{ ampere turns}$$

Using a 5 turn coil:

$$\text{magnetizing current} = \frac{15,000}{5} = 3000 \text{ amperes}$$

Determine the magnetizing current for an article that is 16" long with a diameter of 2". Assume that you are using a 5 turn coil.

Turn to the next page to check your answer.

Your answer should be figured as follows:

$$\frac{L}{D} = \frac{16}{2} = 8$$

$$\frac{45,000}{8} = 5625 \text{ ampere-turns}$$

Using a 5 turn coil,

$$\text{magnetizing current} = \frac{5625}{5} = 1125 \text{ amperes}$$

If your answer was not correct, return to the previous page and recheck your figures.

Use of the formula is predicated on several assumptions:

a. An article greater than 18 inches long requires more than one coil shot.

b. The cross section of article is not greater than one-tenth the area of the coil opening.

c. The article has an L/D Ratio of between 2 and 15.

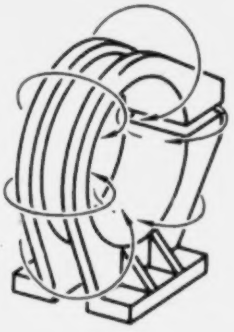
d. Article is placed against the inside wall of coil and not positioned in the center of the coil.

The last one is very important because the magnetic field strength is greatest at the inside wall of the coil. There is a dead spot at the center of the coil.

Turn to the next page.

From page 3-45

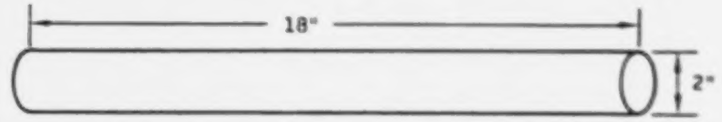
The lines of flux around the coil tend to concentrate close to the coil. Therefore, flux density is greatest near the inside wall of the coil.



Since there is a dead spot in the center of the coil, an article which is to be magnetized is always placed so that it is in contact with or near the inside wall of the coil.

Turn to page 3-47.

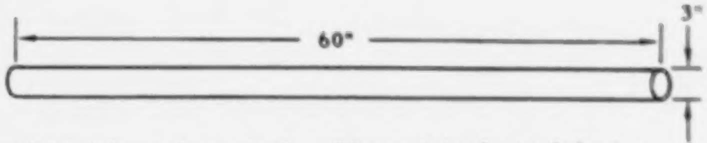
From page 3-46



1. Here is a round steel bar. We have been asked to test it for any possible cracks. First we will magnetize it between the heads. How much current will be required?________________.

---

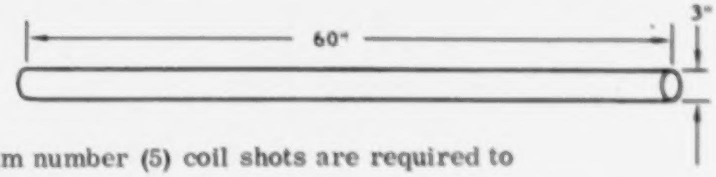
2. 1000 amperes



3. Here is a rod that has been machined from bar stock. The original stock had a seam in it and we have been asked to determine if the seam was removed by the machining process. How would you magnetize the article, and how much current would you use?____

---

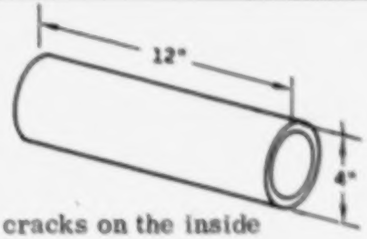
4. 4, 5



5. Considering that the maximum number (5) coil shots are required to longitudinally magnetize the axle, what is the current required for each shot using a 5-turn coil?________________

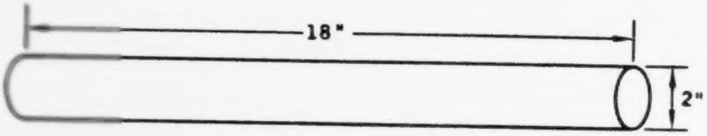
---

6. central conductor,
2400 to 3200 amperes



7. We are then asked to determine if there are any other cracks on the inside surface of the pipe. How would you magnetize it?______________________.

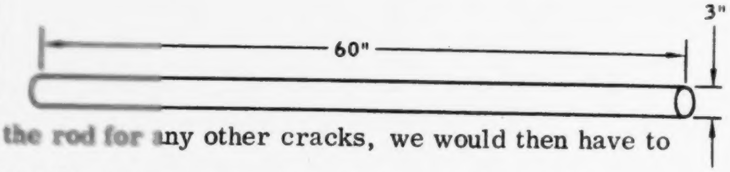
1. 1200 to 1600 amperes



2. Next we will magnetize the bar in a 5-turn coil. How much current will be required?__________

Return to page 3-47, frame 3.

3. Between the heads,
1800 to 2400 amperes

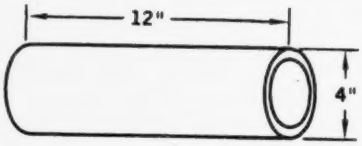


4. If we were asked to inspect the rod for any other cracks, we would then have to "shoot" it with a coil. What is the minimum number of shots that would be required?__________. What is the maximum number of shots required?________________.

Return to page 3-47, frame 5.

5. $\frac{45000}{12/3} = 11,250$ ampere turns

$\frac{11250}{5} = 2250$ amperes



6. Here is a 12-inch section of a 4-inch pipe. We are asked to determine if there are any seams on the inside of the pipe. How would you magnetize the pipe, and how much current would you use?________________

Return to page 3-47, frame 7.

7. Coil shot

8. Turn to page 4-1.

Particles used in magnetic particle testing are made of carefully selected ferromagnetic materials of proper size, shape, and magnetic permeability. These particles retain practically no residual magnetism. The particles are much smaller than iron filings. In fact, when the particles are dry, they are in a flour-like, powder form. The particles are classed in accordance with the way they are used, either WET or DRY.

WET BATH METHOD

With the wet bath method, the particles are suspended in either a water or oil bath. The particles are stirred to keep them evenly distributed in the liquid. The liquid is also pumped through a hose so that it may be directed over the article to be magnetized as shown above.

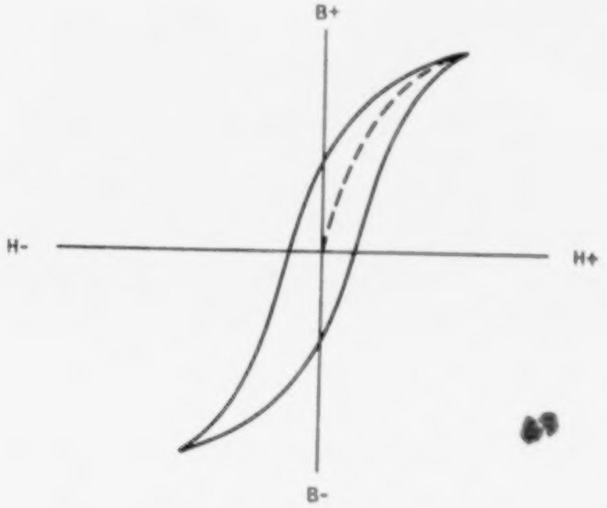
Magnetic particles for the wet bath method are provided in black, red, and fluorescent coatings. The black and red particles provide a color contrast against the background of the article to be magnetized. The particles in the bath will be attracted to flux leakage but, when no flux leakage exists, the particles will flow off the article with the bath. An accumulation of the particles at flux leakage provides an indication of a crack.

Turn to the next page.

From page 4-1

Fluorescent particles for the wet bath method are used with an almost invisible light called "black light." When viewed under "black light", fluorescent particles which have accumulated at flux leakage will glow with great brilliance and provide an indication of a discontinuity. The main advantage of fluorescent particles is their increased visibility under black light.

Magnetic particles of high permeability are required to assure that even weak leakage fields will attract and hold the particles. In general, low retentivity particles are required so they will lose their magnetism. In this way, they are easily removed from the article if they are not held by a leakage field. Particles with these qualities would have a hysteresis loop like this.



From the hysteresis loop, you can tell that magnetic particles used in magnetic particle testing would:

Require a very high coercive force . . . . Page 4-3
Require a very low coercive force . . . . Page 4-4
Require high retentivity . . . . Page 4-5

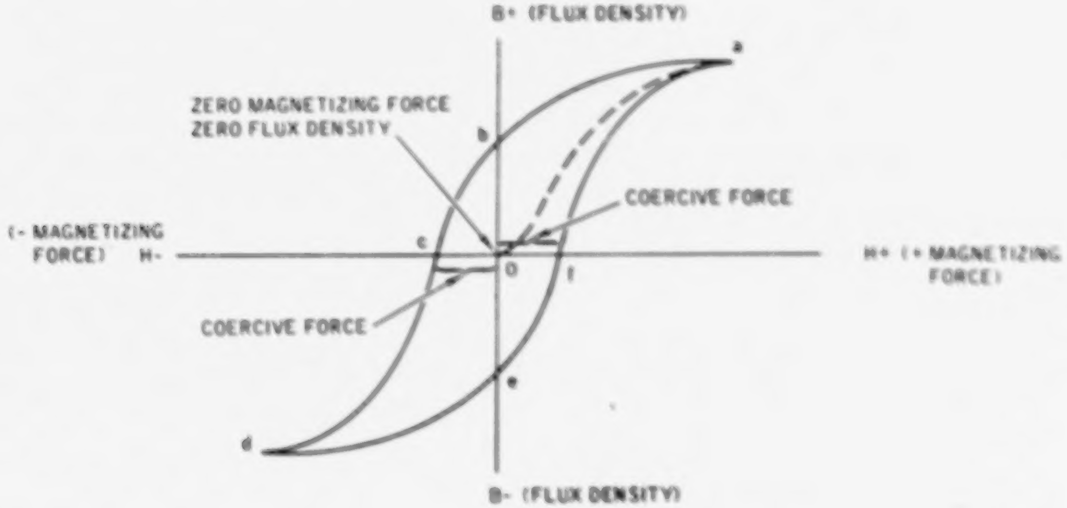
From page 4-2

You feel that magnetic particles would require a very high coercive force. You must have forgotten the definition of coercive force.

COERCIVE FORCE IS DEFINED AS:

> THE REVERSE MAGNETIZING FORCE REQUIRED TO REMOVE THE RESIDUAL MAGNETISM FROM THE MATERIAL.

On the hysteresis loop, the coercive force is shown at two points.

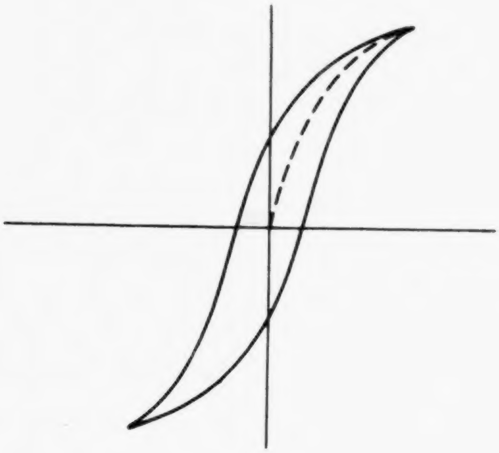

B+ (FLUX DENSITY)
a
ZERO MAGNETIZING FORCE
ZERO FLUX DENSITY
b
COERCIVE FORCE
(- MAGNETIZING FORCE) H-
c
0
f
H+ (+ MAGNETIZING FORCE)
COERCIVE FORCE
e
d
B- (FLUX DENSITY)

The greater the coercive force, the harder is the material and the greater will be the residual magnetism in the material. The wider the hysteresis loop the harder the material--low permeability. Since magnetic particles used in magnetic particle inspection must have high permeability, a much thinner hysteresis loop is indicated. What happens to the coercive force with a very thin hysteresis loop?

Return to page 4-2 and select the correct answer.

From page 4-2

Absolutely. Magnetic particles would have a very low coercive force. Since the particles retain practically no residual magnetism, they are easily removed from the article if they are not held by a leakage field.



In summary, magnetic particles used in magnetic particle testing must be:

a. Highly permeable

b. Have very low retentivity

c. Require a very low coercive force.

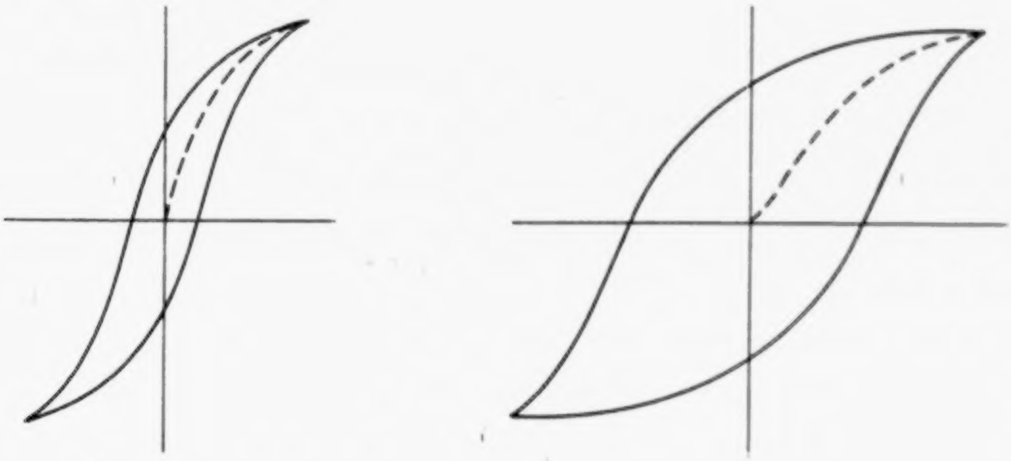
The magnetic particles used in the wet bath method are selected because of their size, shape, color and magnetic properties. They are prepared in the form of a paste which is easily mixed with the water or oil bath. The choice of paste to mix in the bath depends only upon which gives the better color contrast against the surface of articles to be tested. In general, black paste gives a better contrast on new or finished articles, while red gives a better contrast on dark or used articles.

For maximum contrast and maximum sensitivity, fluorescent paste is usually the best to use.

Turn to page 4-6.

You think magnetic particles require high retentivity. No, high retentivity means that the material retains a strong residual magnetic field. Magnetic particles could not be removed from an article if they had high retentivity.

A wide hysteresis loop represents material with high retentivity and a thin hysteresis loop indicates a material of low retentivity.



Return to page 4-2 and select one of the other answers.

From page 4-4

The number of magnetic particles in the bath is called its strength or concentration. If the bath strength is not at the proper level, testing cannot be reliable. If too few particles are in the bath, no indications will be obtained. If there are too many particles in the bath, indications will be masked. Since the proper concentration of particles in the bath is so important, let us now discuss briefly the procedures involved in bath preparation.

Cleanliness of the equipment and the bath is vital for reliable testing. Special attention should therefore be given to cleanliness, as well as accuracy in mixing. The following steps should be followed.

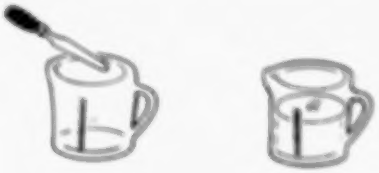
a. Before mixing a new bath, the equipment must be cleaned thoroughly. Remove and clean agitator pipe. Also clean other pipes in the unit and the tank, pump and strainer.

b. After the tank and hose have been cleaned, close all drain cocks and fill tank with oil as recommended by the equipment manufacturer.

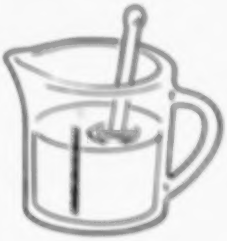
c. Weigh or measure paste into a clean container. The amount of paste used may vary depending on the manufacturer, but typical quantities might be:

1-1/2 ounces of non-fluorescent paste per gallon of oil.

1/4 ounce of fluorescent paste per gallon of oil.



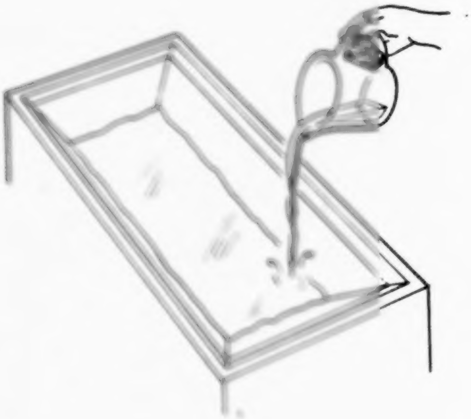
d. Add a small quantity of light oil to paste in container. MIX THOROUGHLY. Repeat until mixture is thin.



Turn to the next page.

From page 4-6

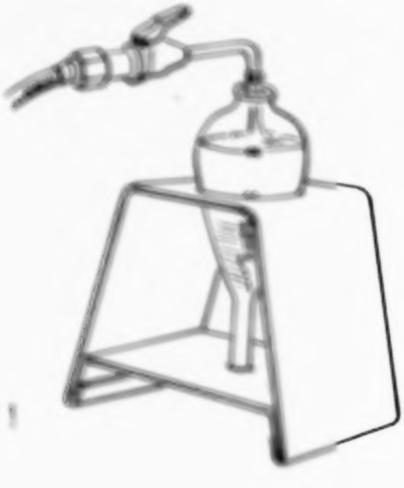
e. Turn on unit pump motor. Pour the mixture from the container into the bath tank.



f. Let pump motor run for several minutes to assure complete distribution of the particles in the bath.

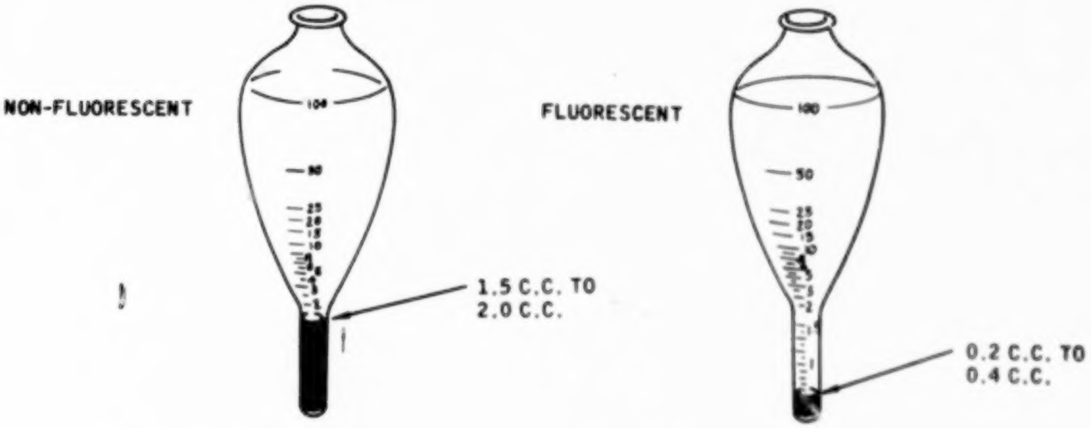
g. Flow bath mixture through hose and nozzle for a few moments to clear hose.

h. Fill centrifuge tube to the 100 cc line.



Turn to the next page.

i. Place centrifuge tube and stand in a vibration free area and allow to remain 30 minutes for particles to settle to bottom of tube.


NON-FLUORESCENT
100
50
25
20
15
10
1.5 C.C. TO 2.0 C.C.
FLUORESCENT
100
50
25
20
15
10
0.2 C.C. TO 0.4 C.C.

j. After 30 minutes, read the volume of particles settled in the centrifuge tube. For non-fluorescent paste, the reading should be between 1.5 and 2.0 cc. For fluorescent paste, the reading should be between 0.2 and 0.4 cc.

If the reading is higher than indicated above, add water or oil depending on the bath in use. If the reading is lower than indicated above, add particles to the bath.

The procedures for checking bath strength should be accomplished every day.

Turn to the next page.

From page 4-8

Particles used in the dry magnetic particle testing method have similar characteristics to those of the wet method except they are in a dry, powder form. Dry particles are also provided in black, red, and fluorescent coatings. The choice of powder to use is determined by which powder will give the greatest color contrast on the object to be magnetized.

Dry magnetic particles depend upon air to carry them to the surface of the article. Here a dry powder spray gun is being used.

DRY METHOD

The method of dispensing dry magnetic particles in a light cloud from air spray guns gives a high degree of mobility to the particles. As the particles float down upon the object being magnetized they are free to move in any direction and thus may be attracted to very weak leakage fields.

Turn to the next page.

From page 4-9

Whether wet or dry magnetic particles are used, it is absolutely essential that the articles to be magnetically tested are clean and free of dirt, grease, oil, rust, and loose scale. If the articles are not clean, mobility of magnetic particles may be hindered to the extent that the particles may not be attracted to leakage fields.

If the article is not clean, a wet bath may run off an oily or greasy surface. Dirt, grease, oil, rust and loose scale can also contaminate a wet bath. Dry particles will stick to a dirty surface. In addition, articles tested by the dry particle method must also be dry as the particles will stick to a damp or wet surface.

The processes involved in cleaning of the many new types of materials used in aerospace articles is a very large subject in itself. Many different processes are required. It is not our intent to delve into this broad subject here. Rather, the intent is to emphasize the great importance of proper cleaning of articles prior to magnetic particle testing.

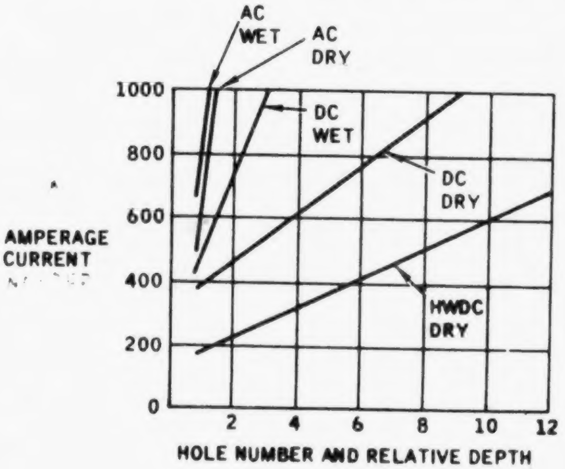
Turn to the next page.

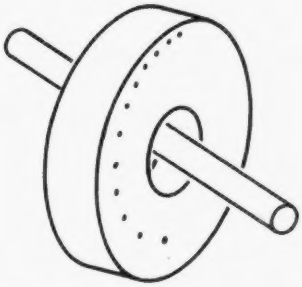
From page 4-10

SENSITIVITY OF METHODS

We have already established the fact that alternating current (ac) is the most effective current to use in detecting surface discontinuities. This is true because ac tends to flow near the surface of an article. Therefore, ac creates the strongest magnetic field at the surface. Since it is acknowledged that ac is superior in detecting surface discontinuities, let us confine our discussion here to the detection of subsurface discontinuities.

The following illustration compares the abilities of the various currents using both wet and dry magnetic particle testing methods in detecting subsurface discontinuities.





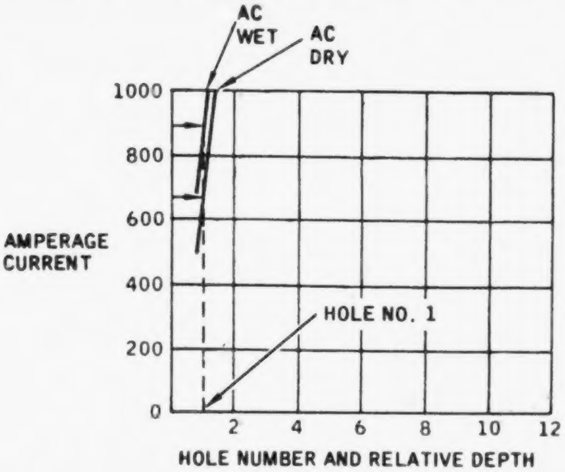
The above chart is based on tests made on a round hollow piece of steel with holes drilled in it at varying depths below the surface.

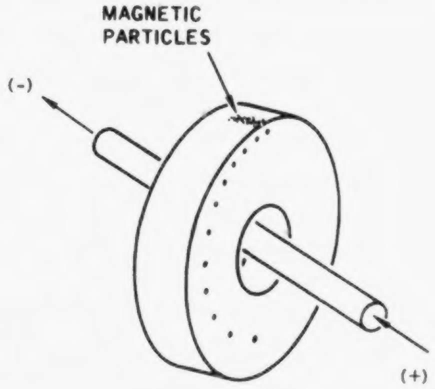
Each test was made using a central conductor and the minimum amount of current of each type to produce a noticeable collection of magnetic particles on the outside surface of the article over any given hole.

Turn to the next page.

From page 4-11

With alternating current, using both wet and dry magnetic particles, between about 700 and 900 amperes were required to cause enough flux leakage to attract magnetic particles on the surface of the article in the vicinity of the first and most shallow hole.



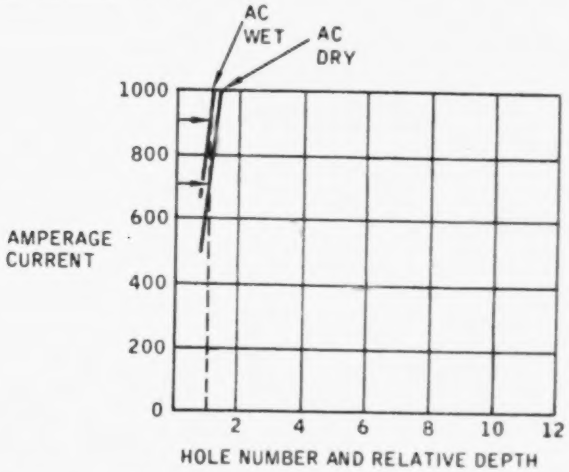


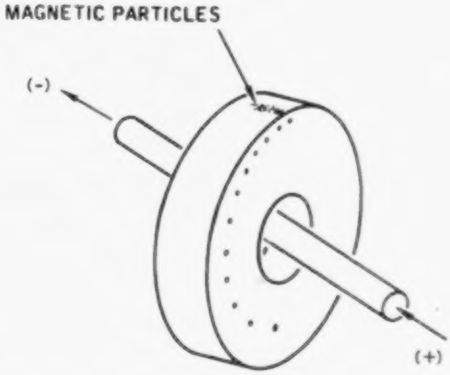
The closeness of the ac wet and ac dry lines indicates there is very little difference between the two methods. It also shows that alternating current is practically of no use in detecting subsurface defects. In spite of its lack of penetration, you can tell from the two lines that alternating current would be most effective using which type of magnetic particles?

Wet bath particles . . . . Page 4-13
Dry magnetic particles . . . . Page 4-14

From page 4-12

You selected--Wet bath particles. We will admit that those lines were very close together but the ac dry line requires less magnetizing current to obtain attraction at hole number 1.



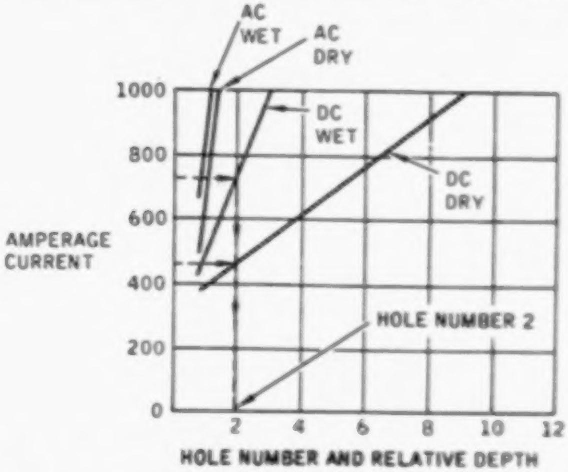


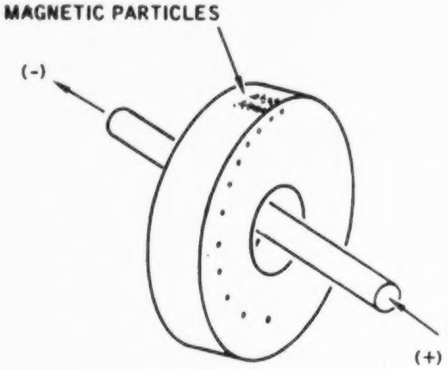
The arrow at about the 700 ampere point on the left scale shows the current required for the ac dry magnetic particles to be attracted to the leakage field created on the outside surface of the article over the first and most shallow hole. In other words, the ac dry line is to the right of the ac wet line indicating the dry particles were more easily attracted to a weaker leakage field. The cyclic pulsing of the alternating current plus the high mobility of the dry particles applied in a light cloud allows the particles to be attracted with a lesser amount of ac.

Turn to page 4-14.

From page 4-12

Right. Because the ac dry line is to the right of the ac wet line, you can see that a lesser amount of ac was required to cause enough flux leakage to attract dry magnetic particles on the surface of the article in the vicinity of the first and most shallow hole. Now let us compare the wet and dry magnetic particles using dc with that of the ac.





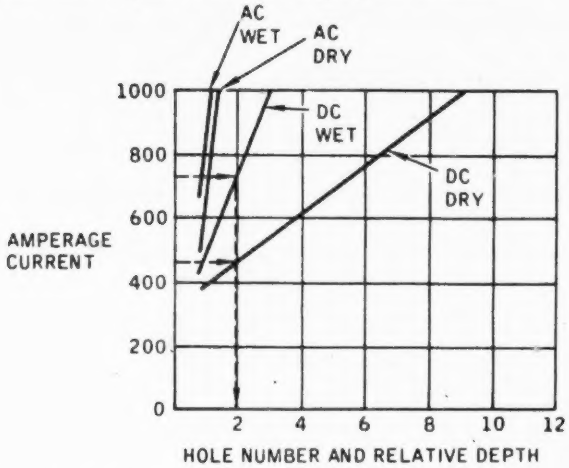
In comparing the two methods, it is important to remember that the minimum amount of each type of current was used to obtain attraction of the magnetic particles. The wet bath method using dc, was able to attract magnetic particles on the surface over the second hole with a minimum current of about 735 amperes. With the use of dry magnetic particles and dc, only 475 amperes were required to attract magnetic particles on the surface at hole number 2.

From the above, we can conclude that whether ac or dc is used, which of the following is true?

Wet bath particles are more easily attracted to flux leakage . . . . Page 4-15

Dry magnetic particles are more easily attracted to flux leakage . . . . Page 4-16

You feel that wet bath particles are more easily attracted to flux leakage. Let's look at that chart again and see if you won't change your mind.



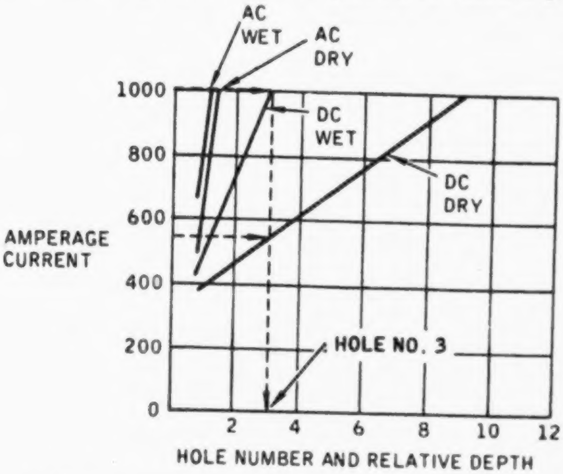
In the cases of both ac and dc, more amperage was required to create flux leakage when using the wet bath method than when using dry magnetic particles. In other words, when using the wet bath method, a stronger magnetic field was required to attract the wet bath particles. On the other hand, less current was required when the dry magnetic particles were used to obtain the same attraction. So you see, whether using ac or dc, dry magnetic particles are the most easily attracted to flux leakage.

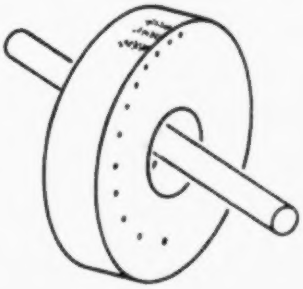
Turn to page 4-16.

From page 4-14

Absolutely. Whether using ac or dc, dry magnetic particles are more easily attracted to flux leakage. This is true because dry particles are blown in a cloud and allowed to drift down lightly to the part being magnetized. This allows the dry particles to be more easily attracted to weaker leakage fields.

With the wet bath method using dc, 1000 amperes were required to cause flux leakage and attract magnetic particles at hole number three. With dry particles and dc, only about 550 amperes were required to attract particles at hole number 3.

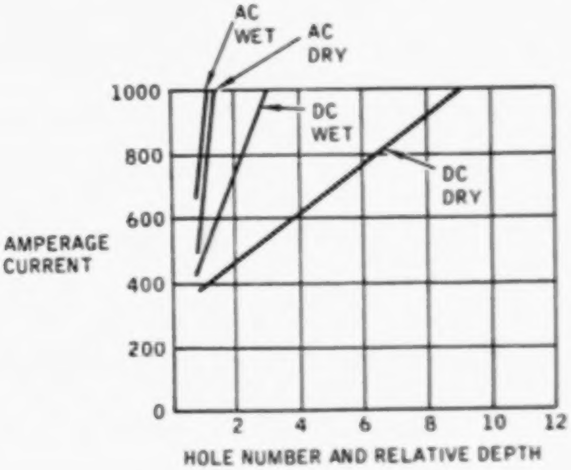




Since dry powder magnetic particles are more easily attracted to weak leakage fields, we can say that they are more sensitive. Which method is most sensitive up to this point?

DC wet . . . . Page 4-17
DC dry . . . . Page 4-18
AC dry . . . . Page 4-19

You think the dc wet method is the most sensitive. Well, dc wet is more sensitive than either ac wet or ac dry but there is a more sensitive method. Let's look at the chart again.



That should give you a clue to the correct answer.

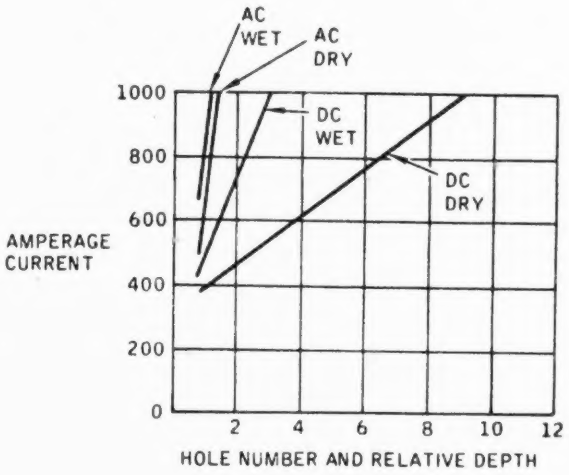
Return to page 4-16 and try again.

Right you are. Straight dc with dry magnetic particles is the most sensitive method up to this point. You seem to have the idea. One thing to remember is that the drilled holes in the test article get deeper and deeper and that an increasingly higher amperage is required to cause a leakage field on the outside surface of the article.

The points to remember are that dry magnetic particles are more sensitive than particles used in the wet bath method whether ac or dc is used.

AC is most effective for locating surface defects. AC is not effective in locating subsurface defects.

DC using dry powder particles is much more sensitive than dc with the wet bath method.



To show the greater sensitivity of dc using dry powder particles, how much amperage would be required for the dc dry method to attract the particles to hole number six (6)?

Approximately 1000 amperes . . . . Page 4-20

Approximately 800 amperes . . . . Page 4-21

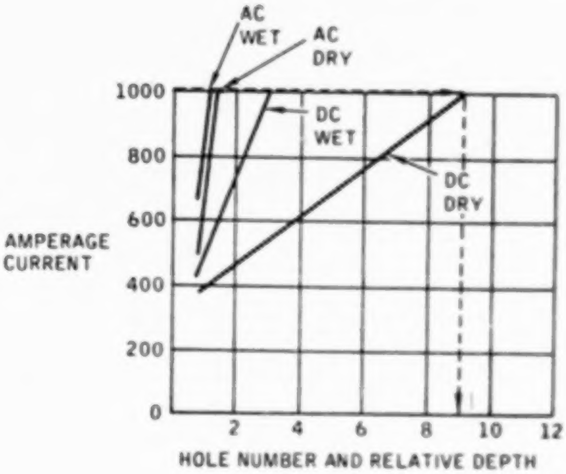
Approximately 600 amperes . . . . Page 4-22

From page 4-16

You think ac dry is the most sensitive method. Admittedly dry powder particles are the most sensitive when used with either ac or dc. But remember that we are now talking about subsurface discontinuities and ac is used only for locating surface discontinuities.

Remembering that dry powder particles are always more sensitive than wet bath particles, return to page 4-16 and pick the correct answer.

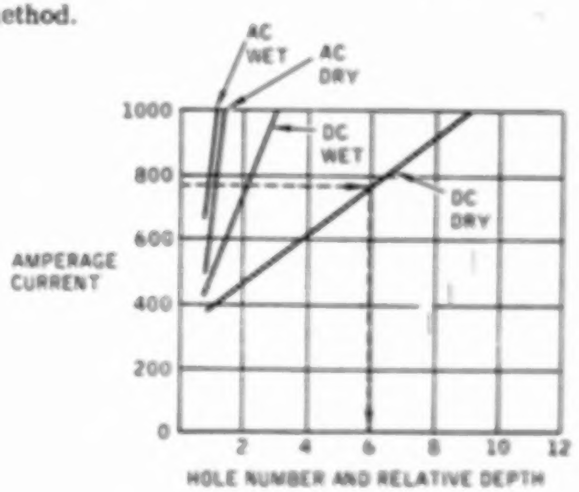
You think it would take approximately 1000 amperes for the dc dry method to attract magnetic particles to hole number six. Ok, let's plot that on the chart and see if you are right.

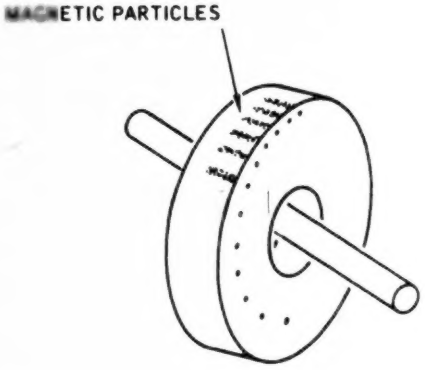


With 1000 amperes, dc using dry powder particles would attract magnetic particles to all holes up to and including number nine. Remember, we are using only the minimum amount of current required to cause flux leakage at an individual drill hole area at the surface. In this case, we want to attract magnetic particles to hole number six.

Return to page 4-18 and try again.

Yes, of course. Approximately 800 amperes would be required to attract the dry particles to the outside surface in the vicinity of hole number 6 using the dc dry method.

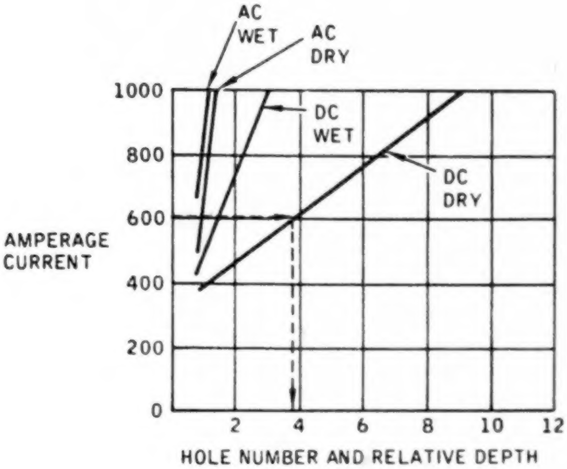




Notice also that the deeper the hole, the more fuzzy and less clearly defined is the accumulation of magnetic particles at the surface of the article.

Turn to page 4-23.

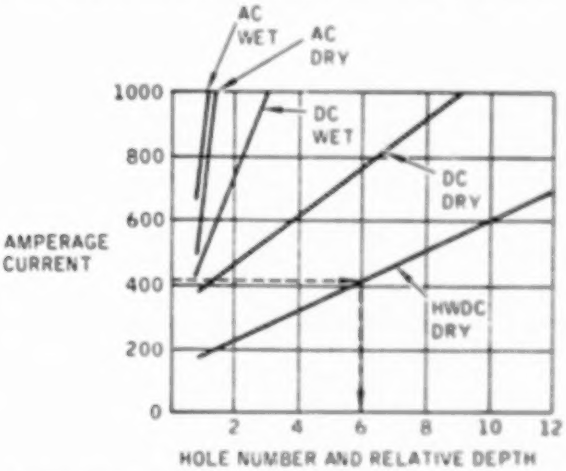
You think it would take approximately 600 amperes for the dc dry method to attract magnetic particles to hole number six. Fine, let's plot it on the chart and see if you are right.



With this plot, you can see that 600 amperes using the dc dry method wouldn't even cause flux leakage at hole number four.

Return to page 4-18 and boost the amperage a bit.

Now let us see where halfwave dc (HWDC) fits into the picture.



Here you can see the HWDC line using dry magnetic particles would require only slightly more than 400 amperes to create flux leakage at hole number 6 in the test article. The conclusion to be drawn here is that HWDC has the greatest penetrating qualities. Because of its continuous pulsing action HWDC agitates the magnetic particles which tends to give mobility to the particles. In this way, the magnetic particles can be attracted to very weak leakage fields.

Turn to page 4-24.

From page 4-23

1. Magnetic particles are classed in accordance with the way they are used, either wet or ________________ .

➡

3. low

4. The magnetic particles retain a very little amount of residual magnetism which means they have very low ________________________________.

➡

6. fields

7. Whether alternating current (ac) or direct current (dc) is used, dry magnetic particles are more easily attracted to flux ___________________________.

➡

9. particles

10. Which method is most effective for location of surface discontinuities?
   a. AC with the wet bath.
   b. AC with dry powder.
   c. DC with wet bath.

➡

1. dry

2. Magnetic particles used in either the wet or dry method must be very easy to magnetize so they are highly ________________________ .

➡

4. retentivity

5. Wet magnetic particles are suspended in a liquid bath while dry particles are carried to the surface of an article by ____________________ .

➡

7. leakage

8. Since dry magnetic particles are more easily attracted to weak leakage fields, we can say they are more sensi________________________

➡

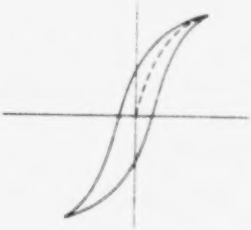
10. AC with dry powder

11. Which method is most effective for location of deep subsurface discontinuities?
    a. Straight dc with dry powder
    b. AC with dry powder particles
    c. HWDC with dry powder particles.

➡

2. permeable

3. The desired qualities of magnetic particles are shown by this hysteresis loop. The loop shows that the particles have a very (high/low) ____________ coercive force.



Return to page 4-24, frame 4.

5. air

6. Dry magnetic particles are blown in a light cloud so they drift down slowly to the article being magnetized. For this reason, the particles are more mobile and easily attracted to weak leakage ______________________________ .

Return to page 4-24, frame 7.

8. sensitive

9. Straight dc using dry particles is more sensitive than when using dc with wet ____________________ .

Return to page 4-24, frame 10.

11. HWDC with dry powder particles.

12. Turn to page 5-1.

We have discussed different types of magnetic particles used in both the wet and dry methods and found they are available in different colors. The different colors can be used to provide the best possible contrast against the background of the article to be magnetized. When these particles are attracted to flux leakage, they can be seen under any ordinary white light.

We have also discussed fluorescent particles which are visible under an almost invisible light called "black light." The "black light" unit is part of the equipment as shown here.

The black light is nearly invisible and when directed on fluorescent particles which have been attracted to flux leakage, the particles will glow with great brilliance providing an indication of a discontinuity.

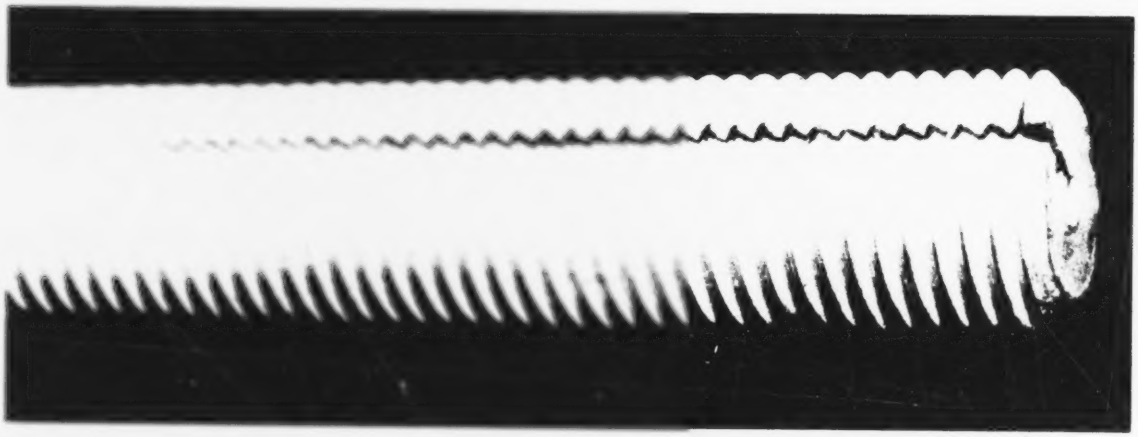
Turn to the next page.

From page 5-1

Now let us discuss some magnetic particle indications provided by both fluorescent and nonfluorescent particles.

To begin with, any accumulation of magnetic particles at flux leakage, provides an indication at discontinuities. In other words, it is the accumulation of magnetic particles that we see and not the discontinuity. For this reason, the accumulation of particles is called an INDICATION. Without the accumulation of magnetic particles, discontinuities are not usually visible to the naked eye.

Illustrated below is an accumulation of magnetic particles at flux leakage in a round rolled bar. These particles are nonfluorescent and would be visible only under white light.



Since the accumulation of magnetic particles is sharp we know this is an indication of a surface crack. Since the crack runs the length of the bar, we know that the particles are giving an indication of which of the following?

Shrink crack . . . . Page 5-3

Seam . . . . Page 5-4

From page 5-2

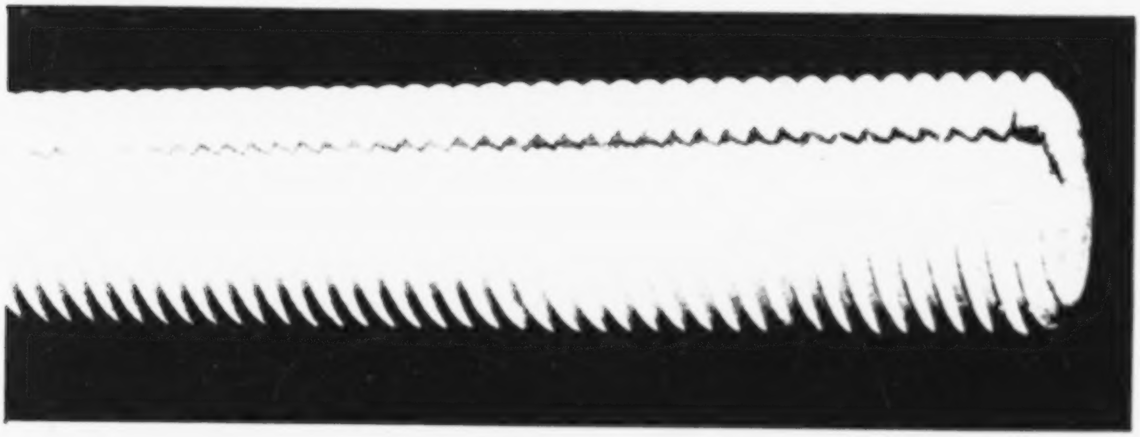
Shrink cracks are usually associated with castings. Not with bar stock such as the round bar in our illustration. In this case the magnetic particles are giving an indication of a seam.

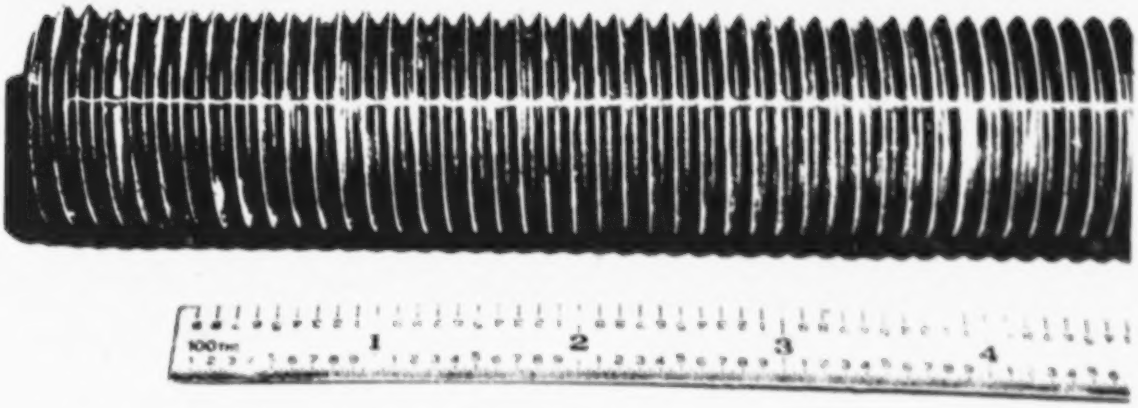
Turn to page 5-4.

From page 5-2

Right. The accumulation of magnetic particles is giving an indication of a seam in the round, rolled bar. Without the accumulation of particles, the seam would not have been visible.

Now let us take a look at that same steel bar and compare the white light visible indication with that of a fluorescent indication.



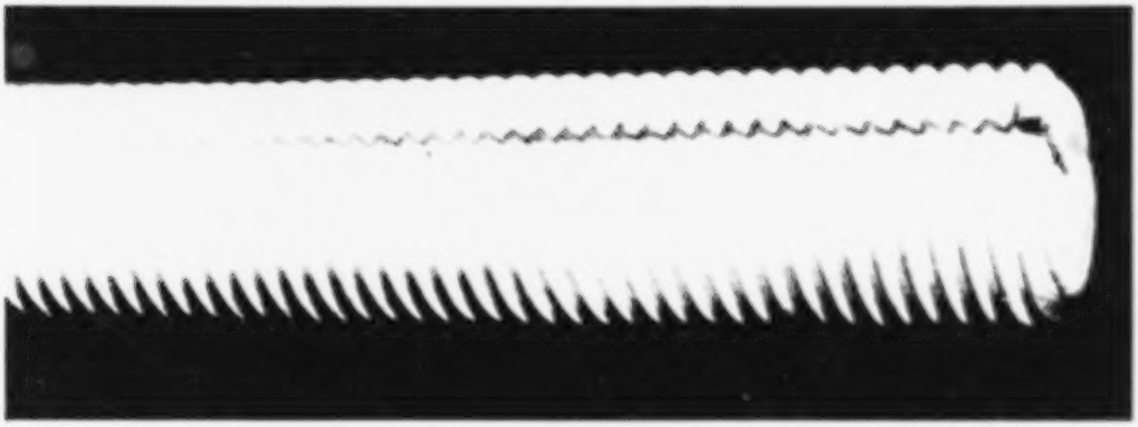


Since you have already seen the white light visible particle indication, you should be able to select the one which shows the fluorescent indication. Which of the above photo's shows the fluorescent indication?

The top photo . . . . Page 5-5

The bottom photo . . . . Page 5-6

You saw this illustration a few pages back.



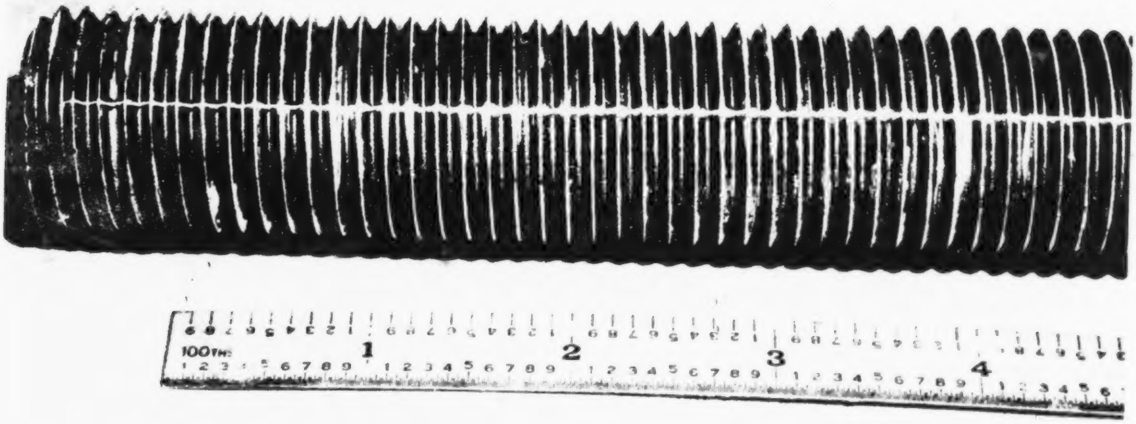
We told you then that it was a nonfluorescent indication viewed under white light.

A fluorescent indication will glow on the dark background of the specimen when viewed under black light. Your choice should have been the bottom photo.

Turn to page 5-6.

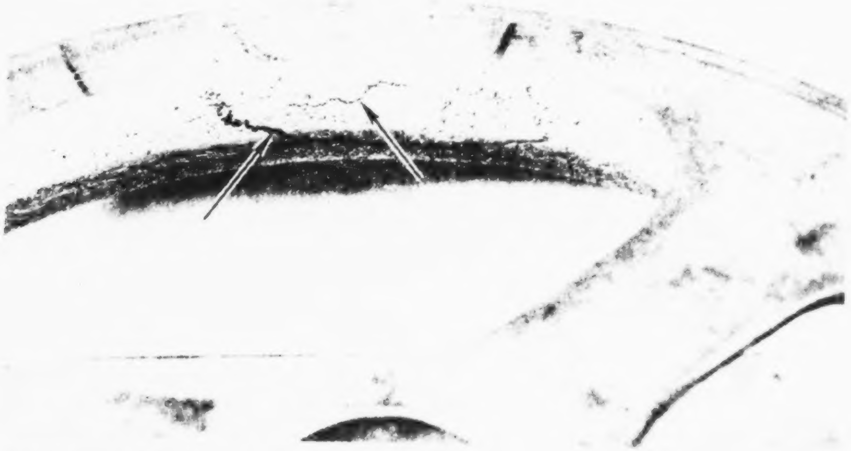
From page 5-4

Sure thing. The bottom photo is the one with the fluorescent indication.



The fluorescent indication glows with great brilliance under "black light". The indication of the seam is very sharply defined.

Here is an indication on a casting made by white light visible particles.



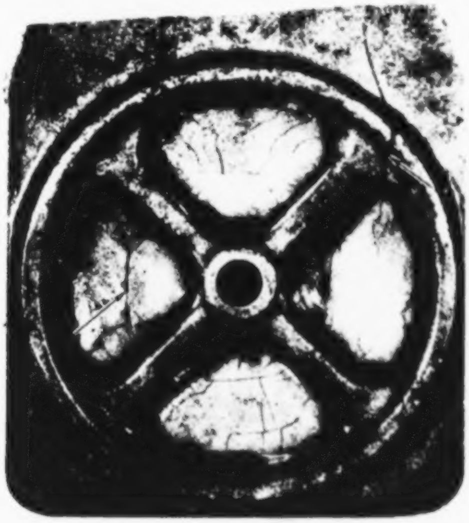
Since the article is a casting, the accumulation of magnetic particles is an indication of which of the following?

Shrink crack . . . . Page 5-7

Seam . . . . Page 5-8

Correct. The accumulation of magnetic particles on the casting is an indication of a shrink crack.

Here is a forging with some magnetic particle indications on it.



The cracks shown by the magnetic particle indications were caused by forging the article at too low a temperature. What is the correct name for the indications?

Forging burst . . . . Page 5-9

Forging lap . . . . Page 5-10

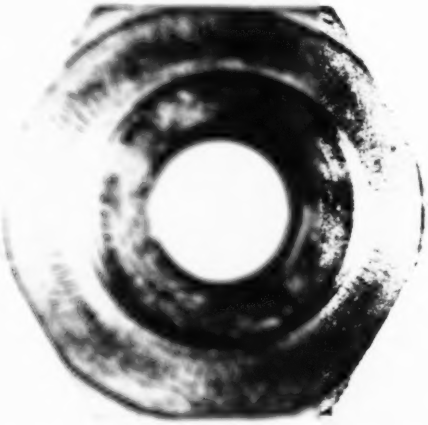
Nope. A seam is caused by a rolling operation in which a discontinuity is flattened and extended. The indications shown are certainly not flat – they are very irregular in shape and direction.

Also, since this is a casting, the discontinuities could not have been formed by a rolling operation.

Turn to page 5-7.

That's right. Those are indications of forging bursts. The forging bursts could not be seen before the article was magnetized. After the article had been magnetized, flux leakage attracted the particles thereby giving a white light visible indication.

Here are some indications on a nut.



The cracks on the nut were caused while the article was being machined. After magnetization, magnetic particles attracted at the flux leakage gave the indications seen above. Which of the following is the correct name for the indications?

Heat treat cracks .... Page 5-11
Grinding cracks .... Page 5-12

From page 5-7

Sorry. Forging laps occur at the mating surface of the dies or at areas of abrupt change in grain direction. They are caused by misalignment of the forging dies.

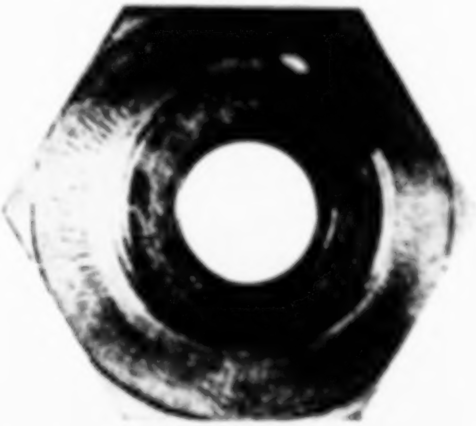
The discontinuities pictured do not meet either of the requirements. They cut across areas of straight grain as well as areas where the grain changes direction.

These are forging bursts.

Turn to page 5-9.

From page 5-9

Think again. These cracks follow a definite radial pattern.



Heat treat cracks do not follow a pattern. They can run in any direction. It is highly unlikely that they would be oriented in the above manner just by chance.

Turn to page 5-12.

Right. Those are indications of grinding cracks. Heat treat cracks would not be oriented in an organized pattern around the article.

Here is an indication on an article which has been machined. The nonfluorescent magnetic particles used in this case, provide a color contrast against the background of the material.

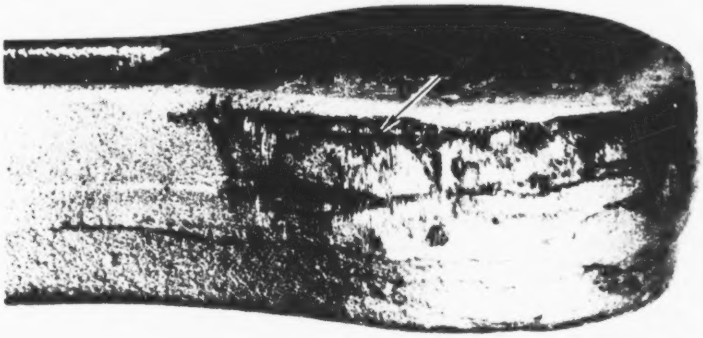
Since this round rolled bar has been machined, which of the following is the most logical name for this indication?

Stringer . . . . Page 5-13

Seam . . . . Page 5-14

Yes, stringer would be the most logical name for the fluorescent indication. Since the article had been machined rather deeply, the indication is probably that of a stringer. A nonmetallic inclusion in the rolled billet from which this article was made, probably formed the stringer. However, it is possible that the indication was that of a seam. Remember, seams are always open to the surface while stringers are usually subsurface.

Now, let us take a look at a forging.



The magnetic particles have been attracted to the flux leakage at this crack in the forging. Which of the following is the correct name for this indication?

Forging burst . . . . Page 5-15
Forging lap . . . . Page 5-16

From page 5-12

Well, it's possible that the discontinuity is a seam. However, since the article has been machined, the indication is more probably that of a stringer.

Remember, seams are always open to the original surface while stringers are usually subsurface.

Turn to page 5-13.

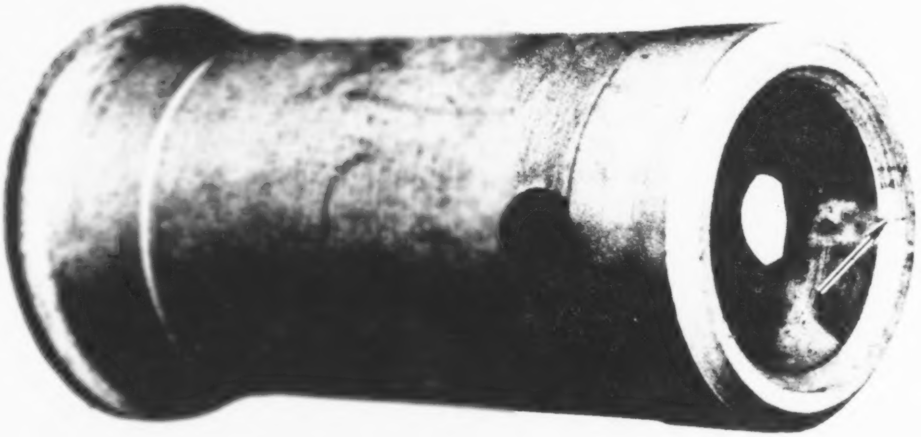
From page 5-13

A forging burst will give a more ragged indication than the one you just saw. So that one is a forging lap.

Turn to page 5-16.

Yes sir. That's a forging lap, alright. The metal has been folded onto the article; probably caused by poor die design. The accumulation of magnetic particles at the forging lap provided an indication that we would see.

Here is an indication of a seam in a hollow steel article.



Magnetic particles have been attracted at the seam giving us an indication that we can see. Considering the fact that the article is hollow, which of the following is the BEST way to magnetize the article to obtain an indication of the seam?

Between the heads . . . . Page 5-17
With central conductor . . . . Page 5-18
In a coil . . . . Page 5-19

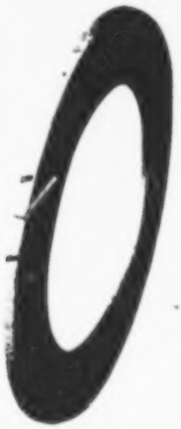
Certainly the article could be magnetized between the heads. But when the electric current is passing through the article, a good magnetic field is not established on the inner surface of the article. Therefore, magnetizing the article between heads would not be the best method for locating a seam on the inner surface of the article.

Return to page 5-16 and select another answer.

From page 5-16

Right. Using the central conductor would be the best method for magnetizing the article so that magnetic particles would give an indication of the seam.

Here is a washer made from a round piece of bar stock. After the article was magnetized, magnetic particles were attracted to the seam indicated by the arrow.



What is the best method to use to locate a seam in this washer?

Between the heads . . . . .Page 5-20
In a coil . . . . .Page 5-21
With central conductor . . . . .Page 5-22

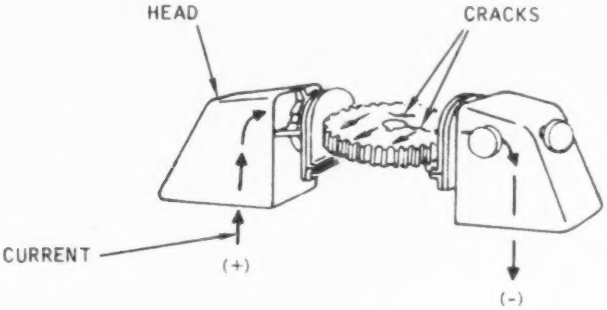
From page 5-16

In a coil the article would be longitudinally magnetized, but the seam would not attract magnetic particles because the seam is parallel to the lines of flux. Remember, cracks must cut across the lines of flux between 45° and 90° to have adequate flux leakage.

Return to page 5-16 and study the problem again.

From page 5-18

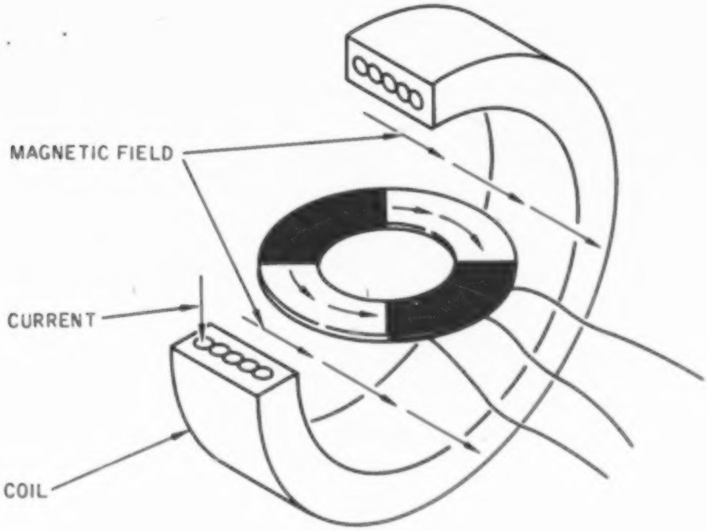
Placing the washer between the heads would cause circular magnetization, but this would only locate cracks that are crosswise as in this gear example.



In the case of the washer with the seam on the outer rim, the lines of force would be parallel to the seam.

Return to page 5-18 and try another answer.

Well, yes, placing the washer in a coil would give a circular magnetic field but only in half of the washer at a time.

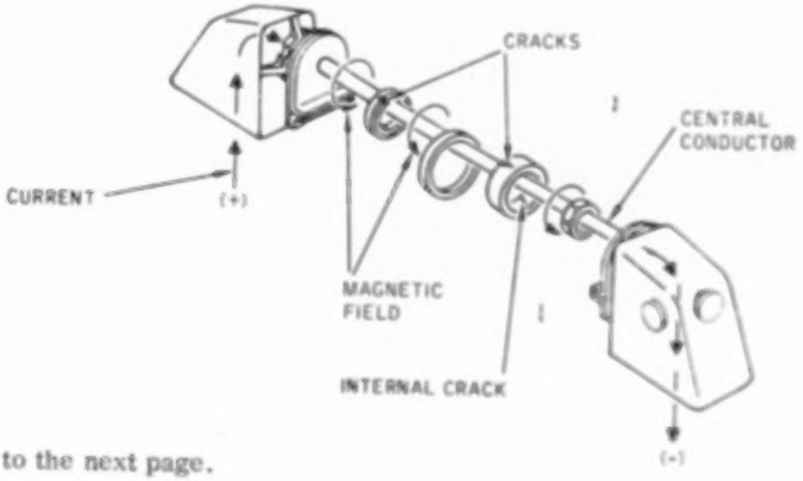


To obtain a satisfactory magnetic field in the dark part of the washer (above) the washer must be rotated 90° and given another shot. There is a better method of doing it.

Return to page 5-18 and try again.

From page 5-18

Right again. You would use a central conductor to locate a seam in that article. Here are other examples of articles where it is perhaps advantageous to use the central conductor.


CRACKS
CENTRAL CONDUCTOR
CURRENT
(+)
MAGNETIC FIELD
INTERNAL CRACK
(-)

Turn to the next page.

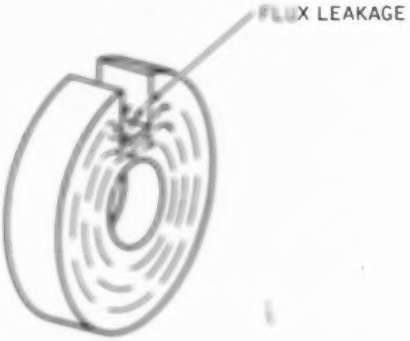
NONRELEVANT INDICATIONS

In previous pages, we discussed surface and subsurface magnetic particle indications of discontinuities. Now we are going to discuss nonrelevant indications--indications caused when magnetic particles are attracted to leakage fields which occur from causes other than discontinuities.

It is very important that nonrelevant indications be recognized for what they are. This is necessary to understand and properly interpret magnetic particle indications.

Nonrelevant indications can be caused by use of excessive magnetizing current, structural design of an article, or variances of permeability within the article itself.

One of the more common nonrelevant indications is caused by a constriction in the metal path through which the lines of flux must pass. Such a constriction is found in an article with a keyway.



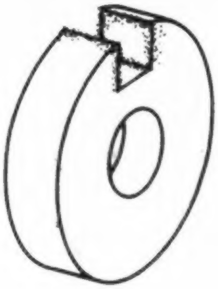
The lines of flux tend to remain in the metal and try to go through below the keyway. However, as the lines of flux are squeezed together, some are forced out of the metal causing flux leakage. Since there is no discontinuity in the metal, do you think magnetic particles will be attracted to the flux leakage?

Yes . . . . Page 5-24

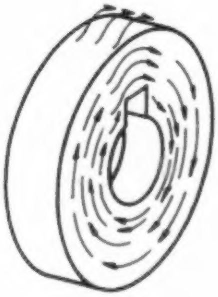
No . . . . Page 5-25

From page 5-23

Yes sir. Magnetic particles will be attracted to the flux leakage. Here you can see the magnetic particles attracted to the flux leakage giving a nonrelevant indication. As with most nonrelevant indications, the indication is fuzzy and not clearly defined.



A keyway on the inside of a hollow shaft may also cause flux leakage. Here again, the lines of flux are forced out of the article by the thinner section at the keyway.



How much flux leakage is created will depend upon the amount of magnetizing current used. Over-magnetization will create a great deal of flux leakage. In this case, what do you think the nonrelevant indication would look like.

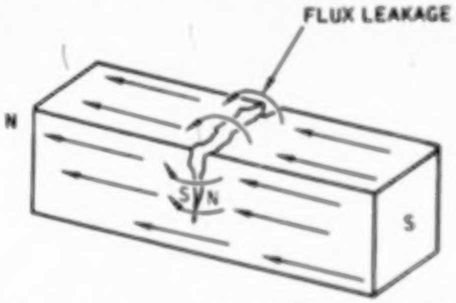
Sharp and clearly defined . . . . Page 5-26
Wide and fuzzy . . . . Page 5-27
Thin and fuzzy . . . . Page 5-28

From page 5-23

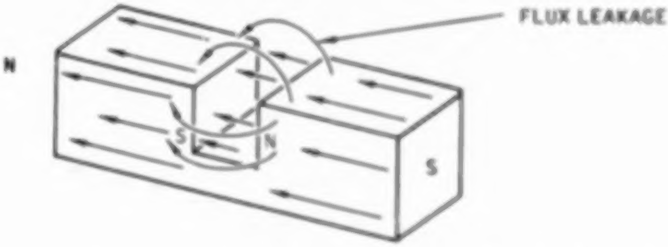
You think that since there was no discontinuity in the metal, magnetic particles would not be attracted by the flux leakage. Let's clarify that point just a little. You may have forgotten one thing:

> AT ANY TIME LINES OF FORCE ENTER OR LEAVE THE METAL, MAGNETIC POLES ARE FORMED AND IRON PARTICLES WILL BE ATTRACTED TO THE FLUX LEAKAGE.

Even a small crack in a bar magnet will disrupt the flow of lines of force and cause flux leakage. Magnetic particles will be attracted at the poles formed at the crack.



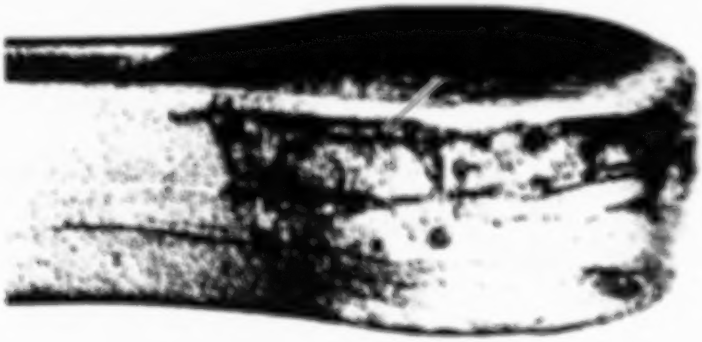
A slot in a bar magnet will cause north and south poles and in turn, flux leakage. Magnetic particles will be attracted at those poles also.



The keyway in the article we were discussing causes flux leakage in the same manner as the slot in the bar magnet. So you see, magnetic particles will be attracted to the flux leakage at the keyway.

Turn to page 5-24.

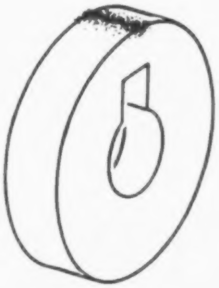
You think the nonrelevant indication would appear sharp and clearly defined. Your answer is only partly correct. It would appear clearly defined but not sharp in the sense we are using the term. Consider this true indication of a forging lap.



The forging lap indication appears as a thin line or sharp as we have used the term. Nonrelevant indications are usually fuzzy and considerably wider.

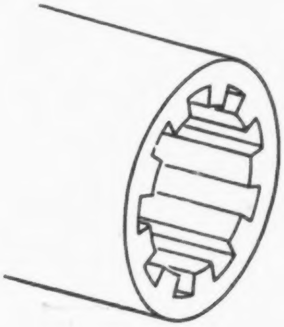
Return to page 5-24 and try again.

Absolutely. Over-magnetization would cause more flux leakage. This in turn would cause a wide and fuzzy nonrelevant indication like this.



Nonrelevant indications where lines of flux are forced out at the surface, as is the case above, are usually fuzzy in appearance and not clearly defined as is the case with a crack or seam.

Here is a section of a shaft with internal splines.

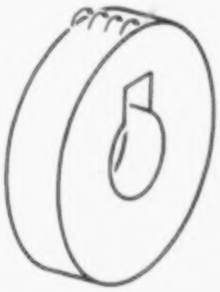


If this article was circularly magnetized, would you expect nonrelevant indications to appear on the outside of the article?

Yes . . . . Page 5-29

No . . . . Page 5-30

Well, it is possible to have a thin and fuzzy nonrelevant indication but only if the amount of magnetizing current is low. In this case, only a small amount of flux leakage would occur.

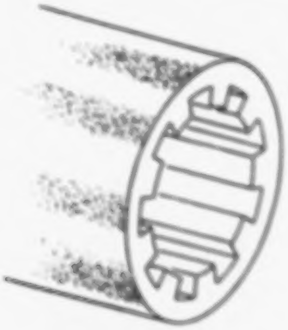


However, in the problem we were discussing, we were over-magnetizing the article.

Return to page 5-24 and try another answer.

From page 5-27

Right. Nonrelevant indications would appear on the outside of the shaft at each of the splines and they would look like this.



Nonrelevant indications like this are usually fuzzy. They do not present a sharply defined indication like heat treat or grinding cracks.

The most common cause for nonrelevant indications is the use of excessive magnetizing current. Too much current causes flux leakage at sharp edges or at abrupt changes of thickness in the article as in the shaft shown above. Much depends on the permeability of the material. Each type of material has a limit to the lines of flux it can hold. When the limit is exceeded, the excessive lines of flux are forced out of the material causing flux leakage. These leakage fields will be apparent first at sharp edges or at abrupt changes of thickness in the article.

Turn to page 5-31.

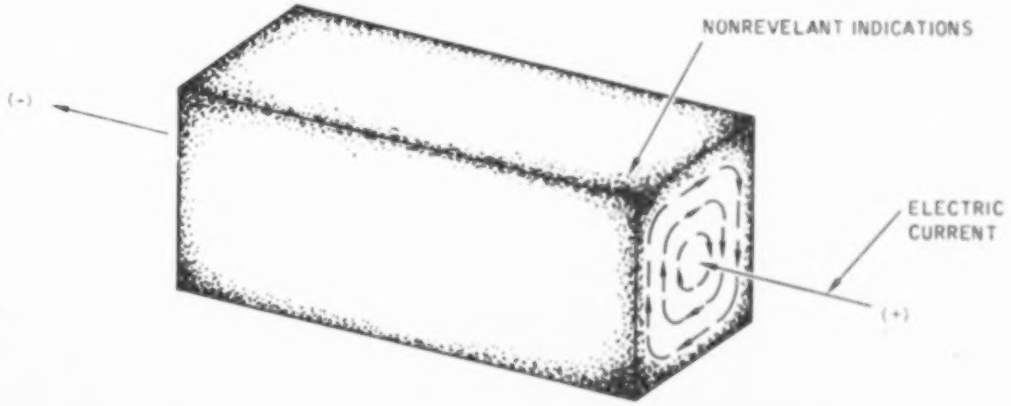
From page 5-27

Well, it certainly would be possible to use a low enough current so that nonrelevant indications would not appear. But if current values prescribed for this article are used, it is very probable that nonrelevant indications would appear on the outside surface of that article in the area of each of the splines. Therefore, a yes answer would be more correct.

It must be remembered, the current values specified for any given article will vary widely. Much of the actual determination of current to be used is dependent upon trial and error methods.

Turn to page 5-29.

Here is an article which is being circularly magnetized by passing electric current through its length. Poles have been created at the sharp edges causing flux leakage. Magnetic particles are attracted to the flux leakage causing nonrelevant indications.



You can see the nonrelevant indications at the sharp edges. What do you think is the cause for the nonrelevant indications on a simple article like this?

Low permeability . . . . Page 5-32

Excessive electric current . . . . Page 5-33

From page 5-31

You think the cause for nonrelevant indications on that article is low permeability. Remember, low permeability means hard to magnetize which means also that the article will retain more lines of force. It is possible, though, to use enough electric current to cause nonrelevant indications on even an article of very low permeability.

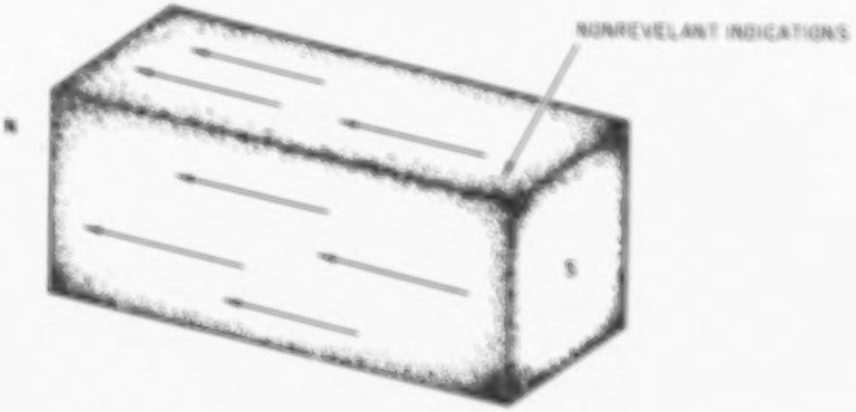
The point we are trying to make is to show the main cause for nonrelevant indications -- it has nothing to do with permeability of an article.

Return to page 5-31 and try again.

From page 5-31

Of course. Excessive electric current caused the nonrelevant indications. When an article is circularly magnetized between the heads, the flux density is greatest at the surface of the article. If excessive current is used, the flux density becomes so great that lines of flux are forced out of the article at the sharp edges. Magnetic particles are attracted to the flux leakage forming the nonrelevant indications.

Longitudinal magnetization has some built-in nonrelevant indications. Any article magnetized in a coil will have at least two magnetic poles.



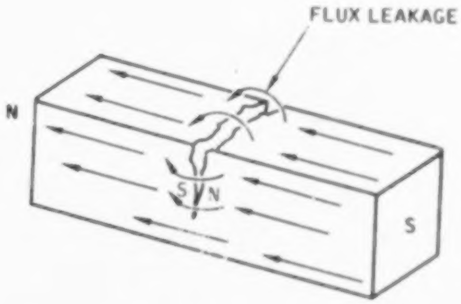
Magnetic particles will be attracted to the poles because that is where the lines of flux enter and leave the article. The nonrelevant indications appear around the edges of the poles because lines of flux tend to leave and enter the article at the thinnest area of the article.

If we cut a slot across the above article, which of the following do you think would happen?

Nothing will happen . . . . Page 5-34

New north and south poles will be formed . . . . Page 5-35

You think nothing would happen if we cut a slot in the article. You missed the point. Remember the principles of magnetic particle testing. If lines of force are interrupted by a discontinuity in the material, magnetic poles and flux leakage will be formed. Magnetic particles will be attracted to the flux leakage.

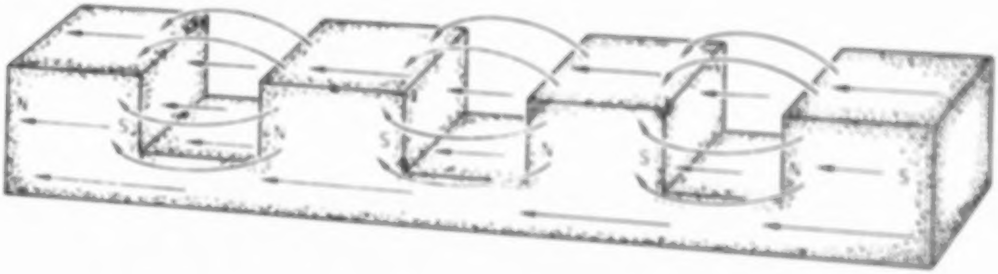


Above you can see the flux leakage and the poles formed at the crack in this material. This is the same condition that would exist if we cut a slot in the article we were talking about. In other words, additional north and south poles will be formed at the slot.

Turn to page 5-35.

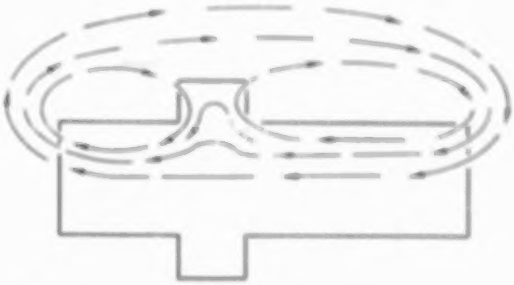
From page 5-33

OK, that's correct. If we cut a slot in the article, additional north and south poles are formed. As a matter of fact, if we cut more slots in the article, poles would form at each slot like this.



Magnetic particles will be attracted to each of the poles causing nonrelevant indications. In each case, the indications will appear around the edges of the poles because lines of flux tend to leave and enter the article at the thinnest area of the article.

Abrupt changes of section thickness of an article longitudinally magnetized, will frequently cause leakage fields which result in nonrelevant indications. Here is an example.



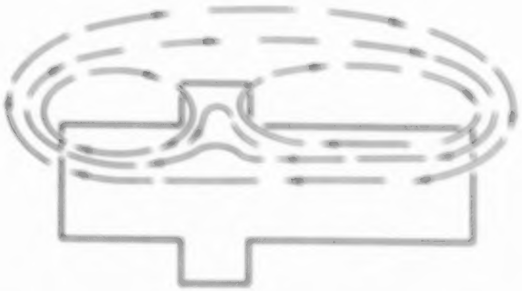
Having been longitudinally magnetized in a coil, this article has magnetic poles at each end which will attract magnetic particles forming nonrelevant indications. In addition, at the point where the thickness increases, the lines of flux tend to expand into the thicker area. This causes local magnetic poles to form at the point where the abrupt change of article thickness is located. The lines of flux continue around, forming a separate closed magnetic circuit on each side of the abrupt change of thickness. Where would you expect nonrelevant indications to appear on this article?

At both ends . . . . Page 5-36

At all points where lines of force leave or enter . . . . Page 5-37

From page 5-35

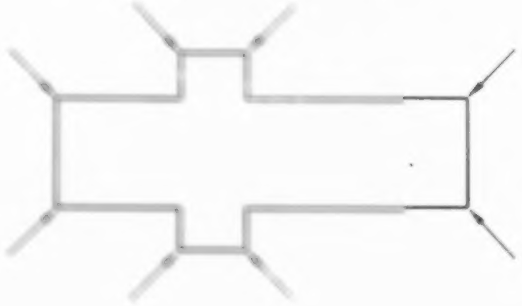
You say that you would expect nonrelevant indications to appear at both ends of the article. The part was longitudinally magnetized in a coil and it would certainly have nonrelevant indications at both ends of the article. This is usually true with uncomplicated articles. However, if there is an abrupt change in thickness, the magnetic field tends to deviate. In other words, the lines of force tend to expand into the thicker portion of the article.



Notice that some of the lines of force leave and enter the article at the point of greatest thickness. These lines of force form a closed magnetic circuit with individual magnetic poles. These local poles will attract magnetic particles causing additional nonrelevant indications. So you see, nonrelevant indications will appear at all points where lines of force leave and enter the article.

Turn to the next page.

Correct. Nonrelevant indications would appear where lines of force leave or enter the article. In this case, lines of force are also leaving and entering the article at the abrupt change of section thickness in the article. As a result, leakage fields would be formed, and nonrelevant indications would appear at the following points.



If the magnetic particle build-up (indication) is excessive at these points, you would know that:

The magnetizing current is too high .... Page 5-38

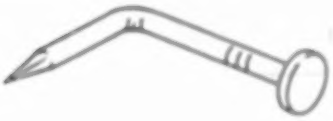
The magnetizing current is too low .... Page 5-39

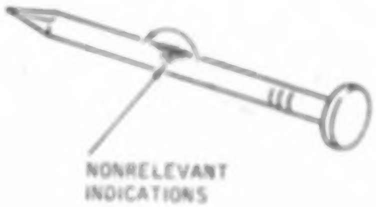
From page 5-37

Yep. The magnetizing current is too high. Excessive magnetizing current is one of the most frequent causes of nonrelevant indications.

Nonrelevant indications frequently occur at sharp fillets and at thread roots. In these cases, the lines of flux tend to jump through rather than follow the extreme change of direction in the metal path. This type of indication can usually be eliminated by reducing the magnetizing current so that it will be slightly below the minimum required for the thickness of the article.

Differences in permeability within the article itself can cause nonrelevant indications. Cold working of metal can change the permeability of the metal. Simply, this consists of changing the shape or size of an article without heating the metal first. Cold working hardens the metal in the area where the change of shape takes place. For example, a bent nail, when straightened with a hammer will be cold worked (hardened) in the area of the bend where it has been straightened. If the nail is then magnetized, the hardened area where the nail was straightened will probably cause flux leakage.





In other words, in the area that has been cold worked, the nail has:

Higher permeability . . . . Page 5-40

Lower permeability . . . . Page 5-41

You selected--The magnetizing current is too low. Actually, it's just the opposite. The greater the magnetizing current, the stronger will be the magnetic field induced into the article. This increases the probability of creating additional magnetic poles and resultant nonrelevant indications. Therefore, if the magnetic particle build-up (indication) is excessive at the points where lines of force enter and leave the article, you would know that the magnetizing current is too high.

When this situation occurs, the article should be demagnetized then remagnitized at a lower current value. Remember, excessive magnetizing current is the most frequent cause for nonrelevant indications.

Turn to page 5-38.

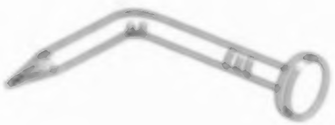
You selected--Higher permeability. You seem to be a little confused about the word "permeability." Let's review its meaning.

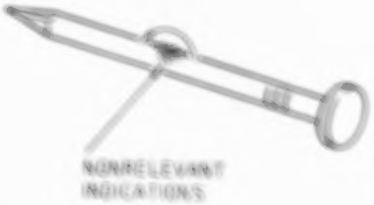
Permeability is defined as:

THE EASE WITH WHICH MATERIALS CAN BE MAGNETIZED.

Soft steel is easy to magnetize and is said to be HIGHLY PERMEABLE. Hard steel is difficult to magnetize and is said to have LOW PERMEABILITY.

Now, back to the problem with the nail. The bent nail, when straightened with a hammer will be cold worked (hardened) in the area of the bend where it has been straightened. If the nail is then magnetized, the hardened area where the nail was straightened would probably cause flux leakage. A nonrelevant indication would probably appear at this point.





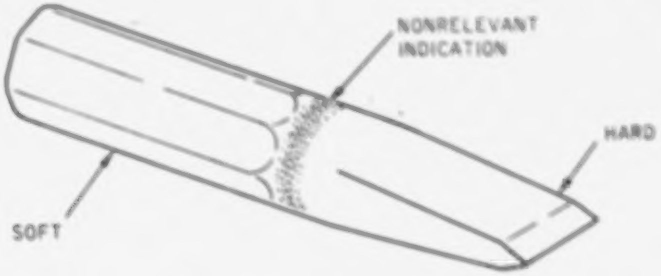
In other words, in the area that has been cold worked, the nail is harder--it has lower permeability.

Turn to page 5-41.

Lower permeability is correct. In the area where the nail had been straightened, the nail would be harder and would have lower permeability. The nonrelevant indication would appear at the hardened area.

Many tools are intentionally made with hard and soft areas. A file for example, is very hard over the cutting portion but the tang or handle is soft.

A cold chisel has a hardened point to cut better and to hold an edge. The head of the chisel is kept softer than the cutting edge so that it won't shatter and break when hit by a hammer. If the chisel is magnetized, a leakage field would probably be formed at the edge of the hardened tip area.



The nonrelevant indication would appear across the shank of the chisel where the hard, heat-treated cutting portion ends and the softer non-heat treated shank begins. This nonrelevant indication is caused by:

Low reluctance of the hard portion . . . . Page 5-42
High reluctance of the hard portion . . . . Page 5-43
High reluctance of the soft portion . . . . Page 5-44

You think the nonrelevant indication is caused by low reluctance of the hard portion of the chisel. Don't let that word "reluctance" throw you. Reluctance means: THE RESISTANCE OF A MATERIAL TO A MAGNETIZING FORCE.

Soft material is easy to magnetize and resists the magnetizing force very little. In other words, soft material is highly permeable.

Hard material is more difficult to magnetize--it resists the magnetizing force. In other words, hard material is difficult to magnetize and has low permeability.

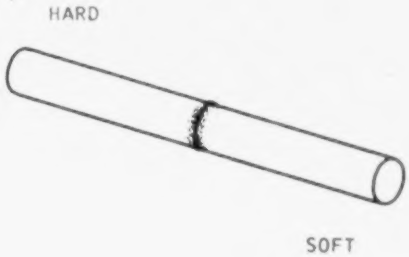
To sum this up, lines of force flow easily in soft material but they tend to jump out of the material if there is a hard point in the material.

Return to page 5-41 and try again.

From page 5-41

Yes, of course. High reluctance of the hard portion caused the leakage field which formed the nonrelevant indication on the chisel. In other words the hard part had a high resistance to the magnetizing force.

The same nonrelevant indication will appear when a hard piece of steel is welded to a softer piece.



If a magnetic field is induced in this part so that it flows across the joint, a strong leakage field will be formed at the joint because of the differences in permeability of the two pieces of material. As a result, a heavy build-up of magnetic particles will be seen at the weld. What can you determine from this type of an indication?

An indication of a defective weld . . . . Page 5-45
An indication of difference in permeability . . . . Page 5-46
The indication gives no information about the weld . . . . Page 5-47

From page 5-41

No, high reluctance of the soft portion is not the cause for that nonrelevant indication. The fact is, the soft part of the chisel has low reluctance.

Reluctance is defined as:

THE RESISTANCE OF A MATERIAL TO A MAGNETIZING FORCE.

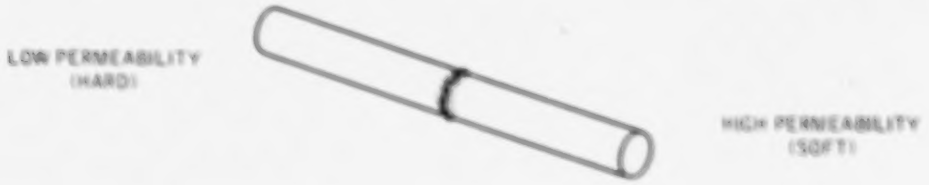
In soft material, the lines of force flow very easily. The material presents very little resistance to the magnetizing force. In other words, the soft part of the chisel has low reluctance.

Hard material is hard to magnetize – it resists the magnetizing force.

In summary, lines of force flow easily in soft material with low reluctance but the lines of force tend to jump out of the material if there is a hard point in the material--a point of higher reluctance.

Return to page 5-41 and study the problem again.

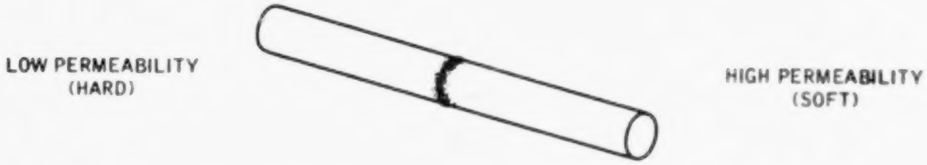
You're guessing. How could there be an indication of a defective weld when there is such a strong indication caused by the differences in the permeability of the two materials?



Actually, it is a nonrelevant indication caused by the differences in the permeability of the material. For this reason, the indication could not possibly provide any information as to whether the weld was defective. The nonrelevant indication would hide any indication of a defective joint.

Return to page 5-43 and select the correct answer.

Fine. You can tell that the indication is caused by differences in permeability.

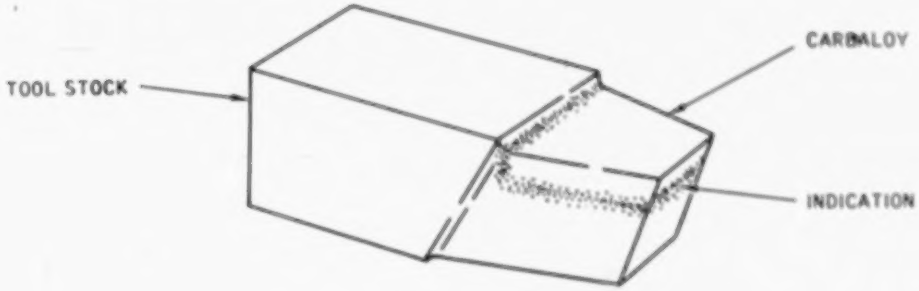

LOW PERMEABILITY
(HARD)
HIGH PERMEABILITY
(SOFT)

Because the indication was caused by differences in permeability first, any indications of a defective weld would be covered up and you could not tell whether or not the weld was a good solid joint. In view of this, the indication can only be classed as nonrelevant.

Turn to page 5-47.

Good for you. The indication gives no information about the weld. Since there is a heavy build-up of magnetic particles caused by the differences in permeability anyway, you could never tell whether the weld was sound.

Another case of this type occurs when two pieces of magnetic material are joined by brazing. The thin layer of brass constitutes a magnetic discontinuity even though the joint may be structurally perfect. Such is the case with this carbaloy tool steel brazed to a piece of tool stock.



This can be considered a nonrelevant indication inasmuch as the indication tells nothing about the brazed joint.

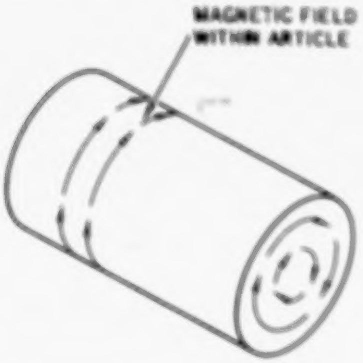
Nonrelevant indications will also appear where tightly fitted parts join. Such is the case where a shaft and pinion are pressed or force fitted together. A nonrelevant indication will be formed where the parts join.

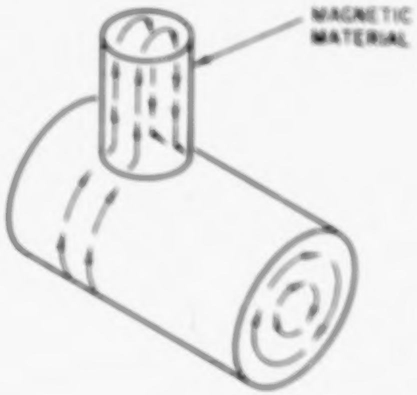
A nonrelevent indication will also form where magnetic materials are joined with non-magnetic material. A magnetic pole is created at the end of the magnetic material and magnetic particles clearly define this area.

Turn to the next page.

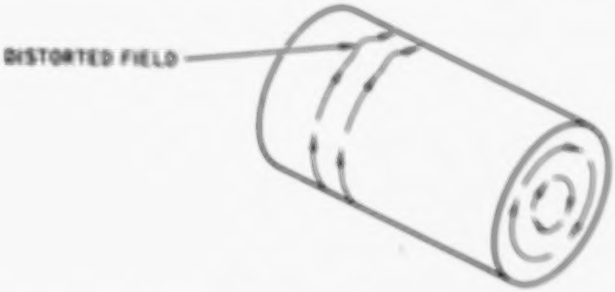
From page 5-47

Magnetic writing is perhaps the easiest nonrelevent indication to create and to interpret. All that is required is that a magnetized article touch another piece of steel which has either no magnetization or is magnetized to a different degree. At the point of contact between the pieces of steel, the magnetic field will be distorted in the magnetized piece of steel causing magnetic poles to form. This shows how magnetic writing is caused.





The part on the left shows the direction of the magnetic field in the article. On the right, you can see the magnetic field being drawn into the smaller piece of steel at the point of contact. This contact distorts the magnetic field. Since there is no force to change the distortion, flux leakage will continue after the smaller piece of steel is removed.



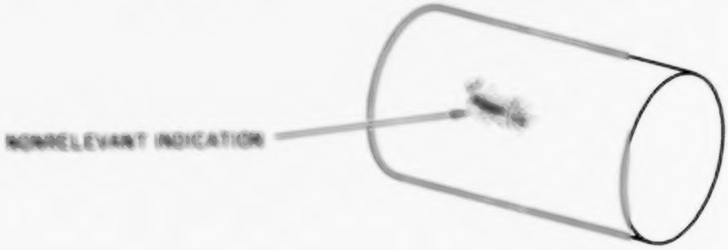
At the point of distortion, magnetic poles are formed. Do you think magnetic particles will be attracted to the flux leakage?

Yes . . . . Page 5-49

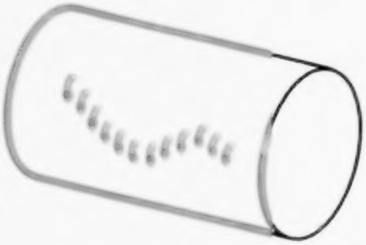
No . . . . Page 5-50

From page 5-48

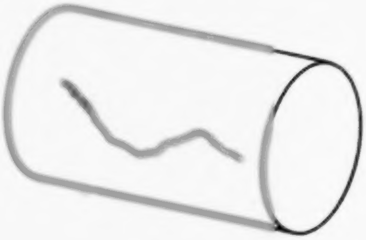
Absolutely. Magnetic particles will be attracted to the flux leakage. Any time magnetic poles are formed, there will be flux leakage and magnetic particles will be attracted. This forms the nonrelevant indication of magnetic writing.



If the piece of steel which caused this indication had been rubbed on the article, the magnetic field would be distorted in a continuous line in the direction of the rub.



The nonrelevant indication resulting from this magnetic field distortion resembles a line or scrawl. The magnetic particles are held loosely and present a fuzzy appearance.

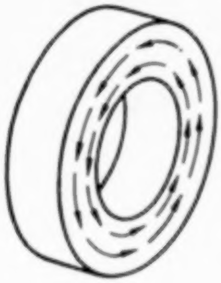


Magnetic writing seldom resembles the pattern formed by an actual discontinuity. The lines may run in any direction. If the article is demagnetized then remagnitized, indications caused by magnetic writing will not reappear.

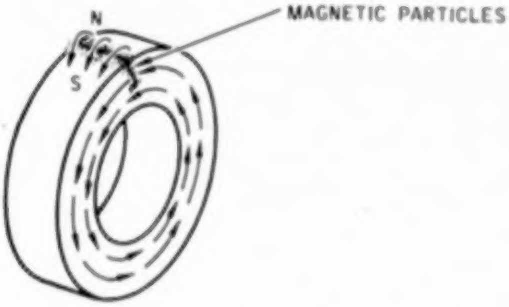
Turn to page 5-51.

From page 5-48

You didn't pay attention on this one. Any time magnetic poles are formed there will be a leakage field and magnetic particles will be attracted to the poles. It acts just the same as with the solid circle magnet with a crack in it. If the complete circle magnet does not have a crack, there will be no poles formed or flux leakage.



However, if the complete circle magnet has a crack in it, magnetic poles are formed at the crack and the lines of force jump through and over the crack causing flux leakage.



So you see, magnetic particles will be attracted to the flux leakage.

Turn to page 5-49.

From page 5-49

ELIMINATION OF NONRELEVANT INDICATIONS

Nonrelevant indications have some fairly distinct characteristics which make them relatively easy to identify under most conditions.

a. The indications are usually "fuzzy" rather than sharp and well defined.
b. Nonrelevant indications can usually be associated with some feature of construction of the article or of its cross-section as in a keyway or sharp increase in section thickness.
c. Nonrelevant indications are usually uniform in direction and size.

Although nonrelevant indications are fairly easy to identify under most conditions, it is possible for them to mask or cover up actual discontinuities. This is particularly true with subsurface discontinuities such as non-metallic inclusions, porosity, stringers, etc., which cause a similar fuzzy indication also. Because of this, it is desirable to eliminate nonrelevant indications whenever possible.

The largest group of nonrelevant indications are caused by using too much magnetizing current. Therefore, nonrelevant indications will usually disappear when the article is demagnetized, then reinspected using a lesser amount of magnetizing current. If a low enough current value is used to re-magnetize the article, the nonrelevant indication will not reappear. Remember too — magnetic writing will not reappear once the article has been demagnetized.

In some cases, it may be necessary to repeat the sequence several times in order to make the nonrelevant indication disappear completely. Each time, the article should be demagnetized, then reinspected using a lower current value.

Turn to the next page.

From page 5-51

FALSE INDICATIONS

False indications are caused when magnetic particles are accumulated and held mechanically or by gravity in surface irregularities. These indications are false because they are not formed by magnetic attraction. Occasionally a false indication is obtained when magnetic particles are mechanically held by a patch of tightly adhering scale on the surface of an article. If the article has a rough surface, is dirty, or is contoured in such a way that magnetic particles collect, an indication may appear in a shape that looks like a true indication. Since false indications are not held by any magnetic force, it is usually possible to tell a false indication from a true one if the particles can be easily removed by light air pressure or by a rinse in a clean solvent.

In summary, false indications are usually caused by:

1. Surface roughness such as scale or slag.
2. Surface contours that are abrupt and not subject to the magnetic field, such as thread roots.
3. Contours that form drainage lines in the wet method.
4. Grease or oil on the surface of the article due to improper cleaning.

Turn to the next page.

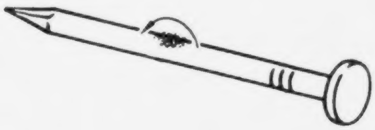
From page 5-52

1. Nonrelevant indications are caused when magnetic particles are attracted to leakage fields which occur from causes other than true dis____________.

12. outside

13. Nonrelevant indications are usually fuzzy and not clearly defined like true indications of subsurface ________________.

24. lower



25. The area of lower permeability in the nail would probably cause a ________________ indication.

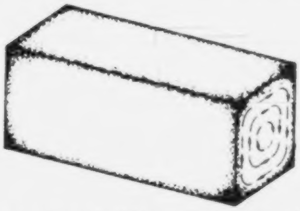
36. will not

37. Although nonrelevant indications are fairly easy to identify, it is possible for them to mask or coverup indications of true ________________.

1. discontinuities

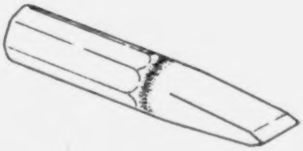
2. Recognition of nonrelevant indications is necessary to understand and properly interpret magnetic particle in____________________.

13. discontinuities



14. If the circular magnetizing current exceeds the permeability of the material, leakage fields will be formed at sharp ____________ of the article forming nonrelevant indications.

25. nonrelevant



26. Many tools are intentionally made with hard and ________________ areas.

37. discontinuities

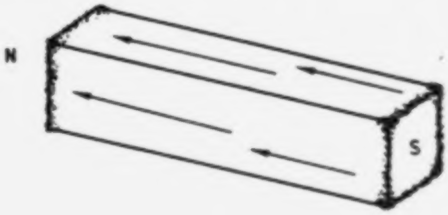
38. Masking or coverup is particularly true with subsurface discontinuities which present a ____________________ appearance also.

2. indications

3. The main cause for nonrelevant indications is excessive magnetizing

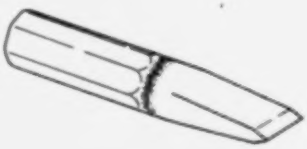
_____________________ .

14. edge



15. Longitudinal magnetization always creates magnetic poles at each end of the article which cause _____________________ _____________________ .

26. soft



27. An indication would form where the soft part of the tool ends and the hard part begins. The nonrelevant indication is caused by the (high or low) ____________ reluctance of the hard part of the tool.

38. fuzzy

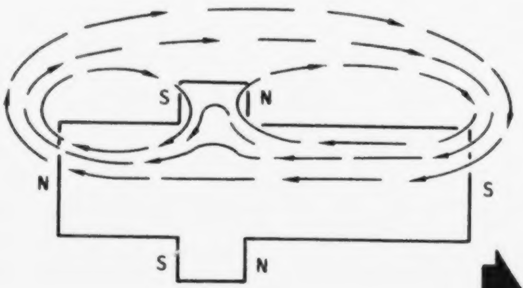
39. Because nonrelevant indications may mask or cover up indications of true discontinuities, it is desirable to elim__________________ nonrelevant indications wherever possible.

3. current

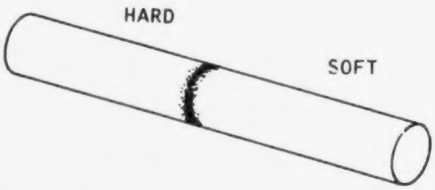
4. Structural design of an article is also a cause for ____________________ indications.

15. nonrelevant indications

16. Longitudinally magnetized articles having abrupt changes in section thickness, will frequently have ____________ fields at the extremities of the thickest part.



27. high



28. If a hard piece of steel is welded to a soft piece of steel and the article is then magnetized, a nonrelevant indication would appear at the ____________ .

39. eliminate

40. Most nonrelevant indications are caused by use of too much magnetizing

____________________ .

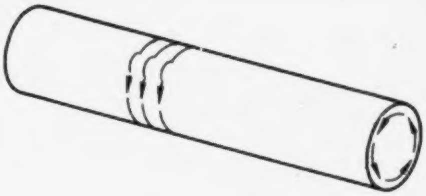
4. nonrelevant

5. Nonrelevant indications due to design of an article can usually be eliminated by demagnetizing the article then remagnetizing with a lower magnetizing ____________________.

16. leakage

17. Magnetic poles are created at the thickest part creating additional closed ____________________ circuits.

28. weld

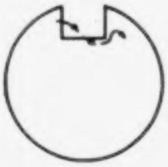


29. The distorted field in this magnetized article was caused when it came in contact with another ferromagnetic article. The distorted field will cause a nonrelevant indication called magnetic__________________.

40. current

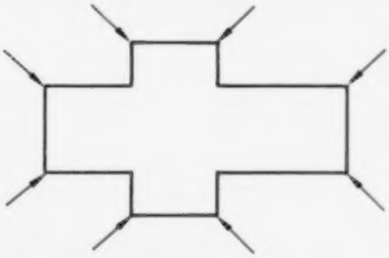
41. Most nonrelevant indications can be eliminated by demagnitizing the article, then remagnetizing the article using a_______________ value of magnetizing current.

5. current



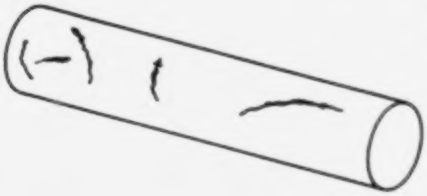
6. A constriction of the metal path through which lines of flux must pass is a common cause of nonrelevant ____________________ .

17. magnetic



18. These separate closed magnetic circuits cause additional ____________________ indications.

29. writing

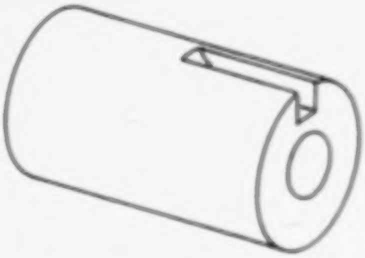


30. Magnetic writing differs from other nonrelevant indications in that the indications may run in any ____________________ .

41. lower (smaller)

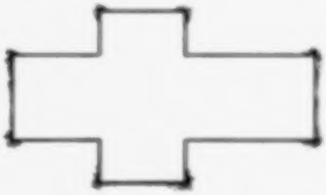
42. If a low enough current value is used to remagnetize the article, the nonrelevant indication will not re____________________.

6. indications



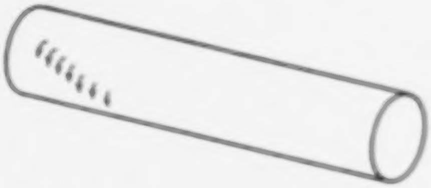
7. An example of a constriction in the metal path is found in an article with a ______________________ .

18. nonrelevant



19. If the magnetic particle build-up (indication) is excessive at these points, you would know the magnetizing current is to ______________________ .

30. direction

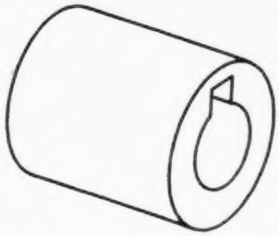


31. If the piece of material which caused the magnetic writing is rubbed on the magnetized article, the magnetic field will be distorted in a continuous line in the ______________________ of the rub.

42. reappear

43. False indications are caused when magnetic particles are accumulated and held mechanically or by gravity in sur______________________ irregularities such as scale.

7. keyway

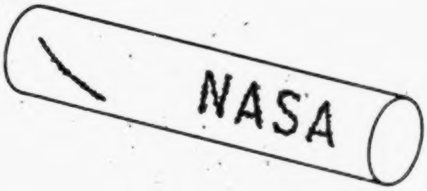


8. A constriction of the metal path is also found in an article with a keyway on the inside diameter which may cause a nonrelevant indication on the ______________ surface of the article.

19. high

20. Differences in permeability within an article can cause ____________________ indications.

31. direction



32. The nonrelevant indication resulting from this ________________ field distortion, will resemble a line or scrawl.

43. surface

44. Indications caused when magnetic particles are accumulated and held mechanically or by gravity are false because they are not formed by leakage ______________ .

8. outside

9. Nonrelevant indications caused by a constriction in the metal path can be reduced or eliminated by demagnetizing then remagnetizing the article with a lower magnetizing ____________________ value.

20. nonrelevant

21. Cold working (hardening) of the metal can change the ____________________ of the metal.

32. magnetic

33. In magnetic writing indications, the magnetic particles are held loosely and present a ____________________ appearance.

44. fields

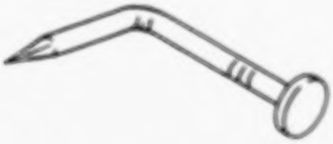
45. Occasionally, a false indication is obtained when magnetic particles are mechanically held by tightly adhering scale on the ____________________ of the article.

9. current

10. Nonrelevant indications are usually fuzzy and not clearly ________________ .

➡

21. permeability



22. A bent nail, when straightened with a hammer, will be ________________ ________________ or hardened in the area where it has been straightened.

➡

33. fuzzy

34. Magnetic writing seldom resembles the indication formed by an actual dis________________ .

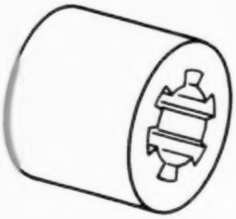
➡

45. surface

46. Inadequate cleaning procedures prior to magnetizing an article is the main cause for ________________ ________________ .

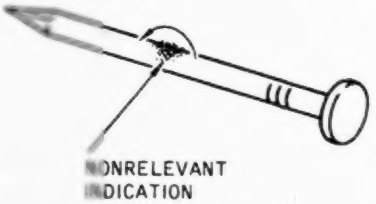
➡

10. defined



11. A shaft with internal splines is another example of a ______________ of the metal path.

23. cold worked



23. If the nail is magnetized, the hardened area would probably cause flux leakage at the point where the nail was stru______________ by a hammer.

34. discontinuity

35. Magnetic writing indications may run in any ______________ .

46. false indications

47. Turn to page 6-1.

11. construction

12. When circularly magnetized, the internal splines in the shaft would probably cause nonrelevant indications on the ________________ surface of the shaft.

Return to page 5-53, frame 13.

23. straightened

24. In other words, in the area that has been cold worked, the nail has ________________________ permeability.

Return to page 5-53, frame 25.

35. direction

36. If the article is demagnetized, then remagnitized, indications caused by magnetic writing (will/will not) ______________________ reappear.

Return to page 5-53, frame 37.

Wet Continuous-Field Method

Now that you are familiar with the types of magnetic particles and the indications provided by particles, let us now discuss the methods used to obtain indications with the WET CONTINUOUS METHOD.

WET BATH METHOD

As you will recall, in the wet bath method, the particles are suspended in either a water or oil bath. The particles are stirred to keep them evenly distributed in the liquid. The liquid is pumped through a hose and directed over the article being tested.

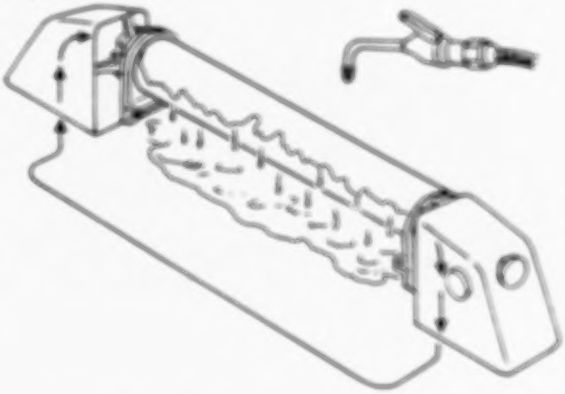
Turn to the next page.

From page 6-1

Before going into the procedures of the wet continuous method, let us review briefly the need for cleaning the article to be tested. It is absolutely essential that the articles to be tested are clean and free of dirt, grease, oil, rust, and loose scale. On an article with an oil or greasy surface, the wet bath may run off the article carrying the magnetic particles with it. Also, any foreign materials washed off the article will contaminate the wet bath. The point to remember is that if the articles are not properly cleaned, discontinuities may be difficult or impossible to locate.

The WET CONTINUOUS METHOD has three steps:

1. Flow bath through nozzle over entire surface of article.
2. Stop bath flow by releasing nozzle handle.



3. Apply current at the instant bath flow is stopped.

With the WET continuous-field method, the article to be magnetized is thoroughly covered with the liquid bath, the bath nozzle is shut off, and then the magnetizing shot is applied immediately thereafter. This procedure ensures that particles will be on the article when the magnetizing current is in the article. If the wet bath is applied while the magnetizing current is on, or after the current is shut off, the force of the bath may wash off lightly held particles at the indications.

When using the wet continuous-field method, the liquid bath is applied to an article at which of the following times?

Before magnetizing shot	Page 6-3
During magnetizing shot	Page 6-4
After magnetizing shot	Page 6-5

From page 6-2

Right. The liquid bath is applied to an article just before the magnetizing shot. If the wet bath is applied while the magnetizing current is on, or after the current is shut off, the force of the bath may wash off any lightly held accumulations of magnetic particles.

Using the wet continuous method, the liquid bath is liberally applied to the article so that all surfaces are wet. The instant that the bath stream is removed from the article, the magnetizing shot is applied.

Why is the liquid bath applied before the magnetizing shot?

To wash off indications . . . . Page 6-6

To prevent washing off indications . . . . Page 6-7

From page 6-2

It is true that there may be occasions when it could be necessary to apply the liquid bath to an article during the magnetizing shot. When to apply the liquid bath during the magnetizing shot will come to you through experience. For our purpose, let us assume that the bath is not applied during the magnetizing shot.

The reason the bath is not applied at this time is that small cracks do not have sufficient flux leakage to hold the particles strongly. If the bath is applied during the magnetizing shot, particles attracted to the cracks with weak flux leakage may be washed away by the bath.

Return to page 6-2 and study the problem again.

From page 6-2

The liquid bath is not applied after the magnetizing shot. Let's look at the procedures again.

The WET CONTINUOUS METHOD has three steps:

1. Flow bath through nozzle over entire surface of article.
2. Stop bath flow by releasing nozzle handle.
3. Apply current at the instant bath flow is stopped.

Return to page 6-2 and try again.

From page 6-3

Oooops! You fell asleep on that one. We do not want to wash off indications.

The liquid bath is applied before the magnetizing shot to prevent washing off lightly-held indications. Small cracks have very weak flux leakage with which to attract the magnetic particles. The force of the bath could wash away the indications at these cracks. That is why the liquid bath is applied before the magnetizing shot.

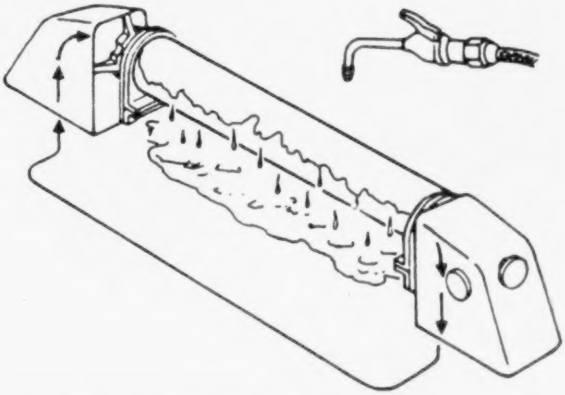
Turn to page 6-7

From page 6-3

Correct. The liquid bath is applied before the magnetizing shot to prevent washing off indications. If the wet bath is applied while the magnetizing current is on, or after the current is shut off, the force of the bath may wash off lightly held accumulations of magnetic particles.

In summary, the WET CONTINUOUS METHOD has three steps:

1. Flow bath through nozzle over entire surface of article.
2. Stop bath flow by releasing nozzle handle.



3. Apply current at the same instant bath flow is stopped.

Turn to the next page.

From page 6-7

Dry Continuous-Field Method

The dry, continuous-field method is used when the article is magnetized using prods, a yoke, or a coil.

The dry, continuous-field method has four steps:

1. Apply magnetizing current.
2. Blow powder particles to magnetized area.
3. Blow excess powder particles off article.
4. Shut off magnetizing current.

The dry powder particles are blown in a light cloud so that they will float to the magnetized area. The floating particles are free to be attracted to any flux leakage at a crack.

Which of the following shows best how dry particles should be applied to the magnetized area?

Powder should float to the magnetized area . . . . Page 6-9

Powder should be forcibly blown onto the magnetized area . . . . Page 6-10

Yes, of course. The powder should float to the magnetized area. If the powder is blown forcibly onto the magnetized area, the particles will not be free to be attracted to any flux leakage.

It is very important that the dry powder particles be blown in a light cloud so that they will float gently to the magnetized area. In this way, the powder is free to be attracted to flux leakage. Now, let us look at the procedure for the dry continuous method again.

1. Apply magnetizing current.
2. Blow powder particles to magnetized area.
3. Blow excess powder particles off article.
4. Shut off magnetizing current.

With the dry continuous method, the powder particles are applied while the magnetizing current is on. With the WET CONTINUOUS METHOD, the liquid bath is applied at which of the following times?

After magnetizing shot . . . . Page 6-11
Before magnetizing shot . . . . Page 6-12
During magnetizing shot . . . . Page 6-13

From page 6-8

Powder that is forcibly blown to the magnetized area is not free to be attracted at flux leakage. In fact, the force of the air may blow the particles right past small cracks with weak flux leakage.

If the powder is blown lightly to form a cloud, the particles settle softly onto the magnetized area. In this way, even weak flux leakage will attract the particles.

Turn to page 6-9.

From page 6-9

There are occasions when the liquid bath may be applied after the magnetizing shot, but we have not yet discussed them. Magnetic particles for the wet or dry continuous method are not applied after the magnetizing shot.

Return to page 6-9 and study the problem again.

From page 6-9

That's right. With the wet continuous method, the liquid bath is applied just before the magnetizing shot. With the dry continuous method, the powder particles are applied while the magnetizing current is on.

Before the magnetizing current is shut off, any excess powder is blown from the magnetized area. If the current is shut off before the excess powder is removed, lightly held indications may be blown off.

Turn to page 6-14.

From page 6-9

You have the answer backward. It is in the dry continuous method that powder particles are blown to the magnetized area during the magnetizing shot.

Return to page 6-9 and try again.

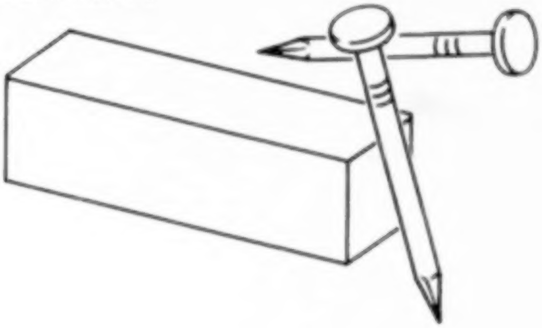
RESIDUAL-FIELD METHOD

When an article made of ferromagnetic material is magnetized, some of the magnetic field remains in the article after the magnetizing current is shut off. The magnetic field remaining in the article is called the RESIDUAL MAGNETIC FIELD.

RESIDUAL MAGNETISM is defined as:

> THE MAGNETIC FIELD WHICH REMAINS IN A MATERIAL AFTER THE MAGNETIZING FORCE IS REMOVED.

Hard metal with a high carbon content will retain the strongest residual magnetic field. A permanent bar magnet is a good example of a very hard metal that retains, or holds, a strong residual field.



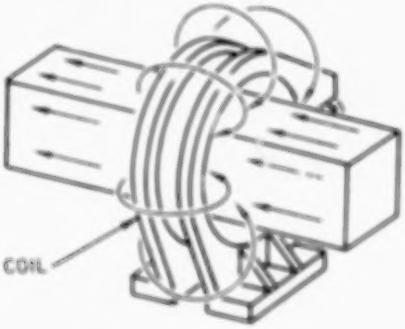
The residual magnetic field in the bar magnet will attract other pieces of iron or steel. A nail attracted to the bar magnet will attract another nail as shown above. The nails are strongly magnetized while in contact with the bar magnet. When removed from the bar magnet, the nails will not attract each other, so we can say the nails are which of the following?

The nails are hard and have a very strong residual field . . . . Page 6-15

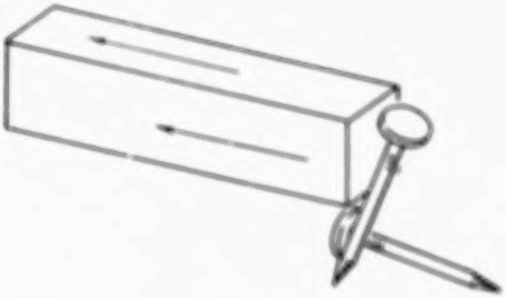
The nails are soft and have a very weak residual field . . . . Page 6-16

You selected — The nails are hard and have a strong residual field. No, it's just the opposite. To clear this up, let's review how a bar magnet is made.

To make a permanent magnet, we first have to select material that is extremely hard. Then the material is magnetized with a very strong field.



After magnetization, the bar will hold a very strong residual field and will attract other materials such as nails.

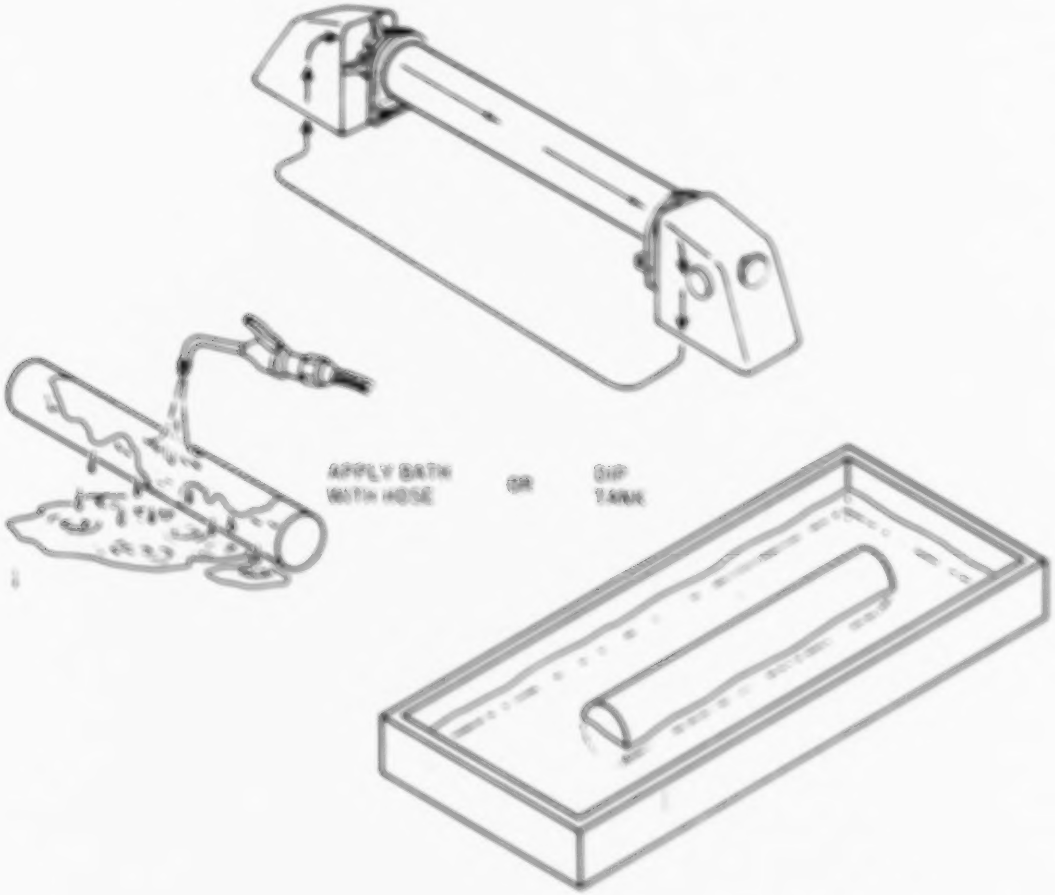


When the nails are removed, they will not attract each other. Nails are soft metal and will retain, or hold, only a very, very weak residual field.

Turn to page 6-16.

Right. The nails are soft and have a very weak residual field. The nails did not hold or retain much of the magnetism after being removed from the bar magnet.

The ability of hard metal to hold or retain the **RESIDUAL MAGNETIC FIELD** is the basis for the residual-field method of testing. A very hard steel article can be magnetized, then removed and tested using the residual magnetic field.



If the above round steel bar had a seam in it, would the residual magnetic field cause flux leakage at a seam?

No . . . . Page 6-17

Yes . . . . Page 6-18

You feel that the residual magnetic field would not cause flux leakage at the seam. Don't forget that, after magnetizing between the heads, we get a circular magnetic field in the article. A seam would run through the length of the article like this.

You can see that the seam runs crosswise (90°) to the lines of flux in the RESIDUAL MAGNETIC FIELD. So the residual magnetic field would cause flux leakage at the seam.

Turn to page 6-18.

From page 6-16

Yes, is right. The residual magnetic field in the round bar would cause flux leakage at the seam. Magnetic particles would be attracted at the seam, and we would have an indication like this.

Magnetization between the heads would cause a circular magnetic field in the article. The circular residual magnetic field would cut directly across the seam at 90° causing flux leakage to attract magnetic particles.

One thing to remember is that the residual magnetic field is always weaker than the magnetic field present when the magnetizing current is flowing. Based on this fact, which of the following do you think would provide the most sensitive testing method?

Residual field . . . . Page 6-19
Continuous field . . . . Page 6-20

From page 6-18

You selected residual field as the most sensitive testing method. "Sensitive" means the method that will provide the best indication.

The residual magnetic field is always weaker than the magnetic field present when the magnetizing current is flowing. The flux leakage from the residual magnetic field would also be weaker. Therefore, there would be less attraction for magnetic particles, and the indication by the particles would not be so pronounced. So, you see, the continuous-field method would provide the most sensitive testing method.

Turn to page 6-20.

From page 6-18

Correct. A continuous field would provide the most sensitive testing method. The magnetic field produced in an article while the electric current is flowing is always the strongest, so the flux leakage would also be strongest.

Turn to the next page.

From page 6-20

MAGNETIC PARTICLE TESTING LIMITATIONS

Up to this point, we have discussed methods of establishing and using a magnetic field to locate discontinuities in articles. There are some limitations to the magnetic particle testing method and we are going to discuss these now.

Magnetic particle testing will locate all discontinuities on the surface and, under some conditions, those under the surface in ferromagnetic materials. In other words, any material that can be magnetized can be tested by this method.

The first limitation, then, is that non-magnetic materials cannot be tested with the magnetic particle testing method. If the material cannot be strongly magnetized, discontinuities will not form magnetic particle indications.

The more common non-magnetic metals are: aluminum, magnesium, brass, copper, lead, bronze, titanium, and most stainless steels.

Which of the following would be the most logical thing to use in determining whether or not an article could be magnetized?

Small bottle of magnetic particles . . . . Page 6-22
Small magnet . . . . Page 6-23

From page 6-21

The small bottle of magnetic particles would not help unless the unknown article were already permanently magnetized in such a way that produced leakage flux. If the article were permanently magnetized, the particles would stick and you would know that the article was made of magnetic materials. But, this is the long way around the barn.

Turn to page 6-23.

From page 6-21

Right. If the small magnet was attracted to the article, the metal is ferromagnetic and can be inspected using magnetic particle testing procedures. If the magnet is not attracted to the article, the metal is non-magnetic and cannot be inspected by this method.

The first limitation then is that non-magnetic materials cannot be inspected with the magnetic particle testing method.

There are no restrictions as to the shape or size of the article being inspected if the article is made of ferromagnetic materials.

Magnetic particle testing is used to detect all discontinuities at the surface of ferromagnetic materials and, under certain conditions, those which lie completely under the surface. The words "under certain conditions" is the basis for the second magnetic particle test limitation.

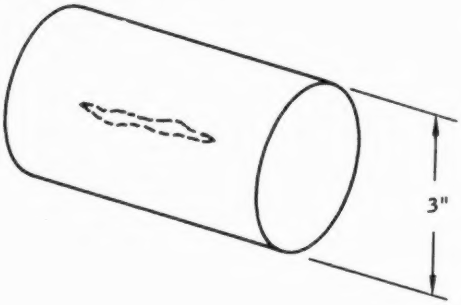
Magnetic particle testing will not detect discontinuities deeper than approximately 1/4 of an inch below the surface.

The 1/4-inch depth limitation is a general rule. Whether a discontinuity can be detected or not will depend upon many things. Permeability of the material being tested, type and location or orientation of the discontinuity in relation to the magnetic field, amount and type of

Turn to the next page.

From page 6-23

magnetizing current used, etc, will ultimately determine whether or not a discontinuity can be detected. For example, here is an internal forging burst.



The internal forging burst is located almost in the center of the round bar. In this case, neither circular nor longitudinal magnetization would cause any large number of lines of force to cut across the burst to create strong flux leakage. In addition, the burst is far deeper in the metal than magnetic particles are capable of indicating.

Turn to the next page.

From page 6-24

SAFETY PRECAUTIONS

Magnetic particle testing techniques do not introduce any hazards which are uncommon to other manufacturing operations. However, it is well to point out the protective measures which should be taken.

The fire hazard and associated precautions are the same with magnetic particle testing as with most other manufacturing operations. Electrical arcing is one exception. Arcing can be caused by poor contact between the heads or by use of excessive magnetizing current. Arcing is most often encountered when using prods or a yoke in the dry particle method. This is caused by poor contact between the prods and the part being magnetized. Arcing can also occur if the prods are allowed to slip. Arçing is most common when using current from such sources as arc welding equipment. This presents a serious hazard to the eyes or skin from arc "flashes," or "burns." Safety glasses should be worn when using the dry method and the equipment should not be used in an area where combustible gases or vapor may be present.

Oils and pastes used in the wet bath method are not directly irritating to the skin. However, continuous exposure may cause rash or cracking of the skin. Protective compounds in the form of paste can be applied to hands or skin where the skin comes in continuous contact with the bath. These compounds are insoluable and give good protection particularly if renewed occasionally. Neoprene gloves will also afford protection although they may be somewhat cumbersome.

If water is used for the wet bath, care should be taken to assure that the equipment is well grounded to prevent electrical hazards.

Dry magnetic particles used in the dry method are non-toxic but care should be taken to avoid inhaling excessive amounts. Since the dry particles float freely in the air, they are easily inhaled and a dust respirator should be used if the dry particles are to be used for an extended period of time.

Turn to the next page.

From page 6-25

Smoking or use of any open flame should be prohibited near equipment using an oil bath. Although the oils commonly used have a high flash point (the point where they vaporize and become combustible), the possibilities of fire are always existant. In this regard, oily rags or materials should be disposed of in suitable containers to prevent creating additional fire hazards.

The black light used with fluorescent particles, will cause no permanent damage to the skin or eyes if the recommended filters are used on the black light. The individual may experience a clouding of vision if the black light shines directly into the eyes or if it is reflected into the eyes. This happens because fluid in the eyes will fluoresce and this causes the clouded vision sensation. When the light no longer shines in the eyes, the sensation will dissappear and there will be no permanent damage.

One of the heads on a wet bath magnetizing unit is usually extended by an air operated cylinder to affect a clamping action on an article to be magnetized. Care should be used in handling articles placed between the heads to avoid crushing the hand.

Safety precautions usually start from a base of good housekeeping practices. A clean work area and clean, well-kept equipment are requisites to the conduct of any non-destructive test performed on aerospace materials or articles.

Turn to the next page.

From page 6-26

REVIEW

1. Whether wet or dry magnetic particles are used, it is absolutely essential that the articles to be tested are free of dirt, grease, oil, rust, and loose scale. In other words, before magnetic particle testing, articles must be ________________.

5. dry

6. If articles are not clean, the magnetic particles may not be attracted to leakage fields and it may be difficult or impossible to locate ____________________ .

10. turned off

11. The residual method works best with material of ____________ permeability because of the________________ residual field in the article.

15. b - c - a

16. What is the proper order of procedure for the dry residual method?

a) Turn magnetizing current off.
b) Turn magnetizing current on.
c) Apply particles.

1. cleaned

2. If the articles are not clean, mobility of the magnetic particles may be hindered to the extent that the particles may not be attracted to leakage ______________ .

6. discontinuities

7. Another reason for cleaning articles before wet bath testing is that foreign materials will con__________________ the wet bath.

11. low
strong

12. With the wet continuous method, the wet bath is applied to the article just before turning on the ________________ current.

16. b - a - c

17. What is the proper order of the procedure for the wet residual method?
a) Turn magnetizing current off.
b) Turn magnetizing current on.
c) Apply particles or bath

2. fields

3. With an oily or greasy surface, the wet bath may run off the article carrying the magnetic ________________ with it.

7. contaminate

8. Both the wet bath and dry powder particles can be applied by one of two methods: continuous or ____________________ .

12. magnetizing

13. In the dry continuous method, the particles are applied while the magnetizing current is (on/off) __________ .

17. b - a - c

18. Magnetic particle testing methods are restricted to the examination of ____________________ materials.

3. particles

4. If an article is oily or greasy, dry particles will stick to the oil and grease on the ________________.

8. residual

9. In materials of high retentivity, the indication may be obtained by using the ______________ ________________ in the article.

13. on

14. What is the proper order of the procedure for the wet continuous method?

a. Turn magnetizing current off.
b. Turn magnetizing current on.
c. Apply wet bath

18. magnetic

19. Magnetic particle testing will only indicate discontinuities that are at or relatively close to the ______________.

4. surface
(part)

5. With dry magnetic particles, however, the article must not only be clean, it must be ___________ also.

Return to page 6-27,
frame 6.

9. residual magnetism
(residual field)

10. With the residual method, either wet or dry, the magnetic particles are applied after the magnetizing current is ________ __________ .

Return to page 6-27,
frame 11.

14. c - b - a

15. What is the proper order of procedure for the dry continuous method?

a. Turn magnetizing current off.
b. Turn magnetizing current on.
c. Apply particles.

Return to page 6-27,
frame 16.

19. surface

20. Turn to page 7-1.

Theory

As explained earlier, magnetizing an article leaves it with a residual magnetic field. This residual field may not be desirable in the article for several reasons. For example, residual fields will affect magnetic compasses or create problems with delicate instruments. Also, residual fields will attract metal particles to rotating articles causing excessive wear or binding. If the article is to be machined, chips may be attracted to the article and interfere with machining operations. These are only a few of the reasons why it is necessary to demagnetize an article. If for no other reason, articles are demagnitized so that all of the magnetic particles used during testing can be removed. "Demagnetization" is the process for removing any residual fields.

Let's see what you remember about residual magnetism.

When an article is first magnetized, the residual field is in the ____________ direction as the magnetizing field.

same . . . . Page 7-2
opposite . . . . Page 7-3

Good! The residual field is in the same direction.

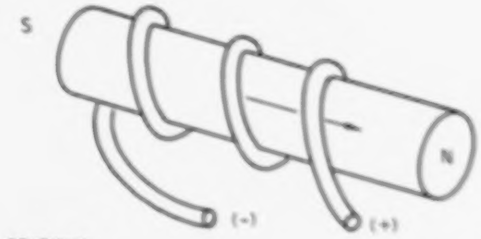
Let's look at another point concerning residual magnetism. Do you remember this? Which word best completes the sentence?

The residual field is _______________ than the magnetizing field.

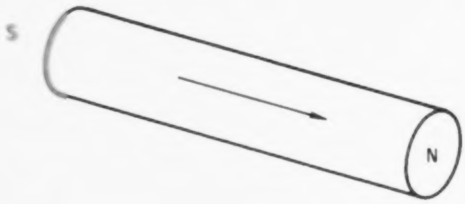
stronger . . . . Page 7-4

weaker . . . . Page 7-5

No! The residual field is in the same direction as the magnetizing field. Here's what we are talking about.



ORIGINAL
MAGNETIZING
FIELD



RESIDUAL
FIELD

Remember, the residual field is always in the same direction as the magnetizing field.

Turn to page 7-2.

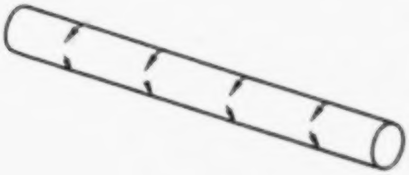
From page 7-2

Nope - it's weaker. If you think about it for a minute, you will realize that we could never get a residual field that was stronger than the original magnetizing field. We can never get more out of a thing than we put into it.

Turn to page 7-5.

Good! The residual field is always weaker than the magnetizing field.

Here is a bar on which we are showing a relatively weak, residual, circular field. This bar was magnetized with a strong, circular, magnetic field. When the magnetizing current was turned off, the original magnetizing force ceased and the weaker residual field was left.



The original magnetizing force caused the residual field.

The original magnetizing force was _______________ than the residual field.

weaker . . . . Page 7-6

stronger . . . . Page 7-7

From page 7-5

Be careful. We've turned the statement around on you.

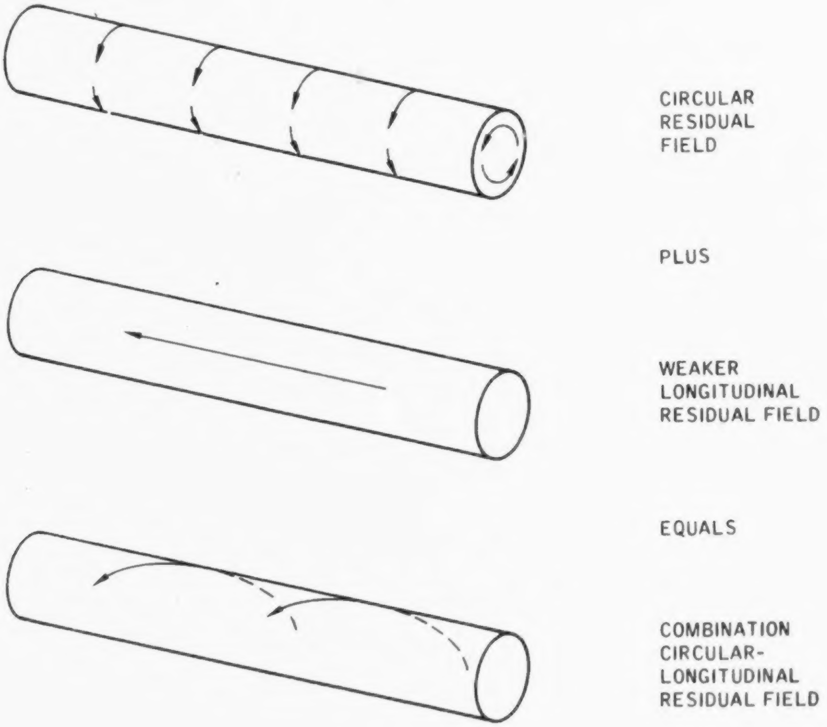
If the residual field is always weaker than the original magnetizing field, it follows that the original magnetizing field is always stronger than the residual field.

Return to page 7-5 and look at the statement again.

From page 7-5

Good. The original magnetizing force was stronger than the residual field.

What happens to the residual field when an article has been magnetized in more than one direction? Let's consider a bar that has been circularly magnetized, then longitudinally magnetized.


CIRCULAR
RESIDUAL
FIELD
PLUS
WEAKER
LONGITUDINAL
RESIDUAL FIELD
EQUALS
COMBINATION
CIRCULAR-
LONGITUDINAL
RESIDUAL FIELD

The circular residual field combines with the longitudinal residual field as shown above. But this combination occurs only if the second field is weaker than the first.

Then, in this case, the original longitudinal magnetizing force must have been ____________ than the original circular magnetizing force.

stronger . . . . Page 7-8

weaker . . . . Page 7-9

BE CAREFUL. This is a tricky question.

We are comparing 4 different things here.

The original circular magnetizing field and its residual circular field.

The original longitudinal magnetizing field and its residual longitudinal field.

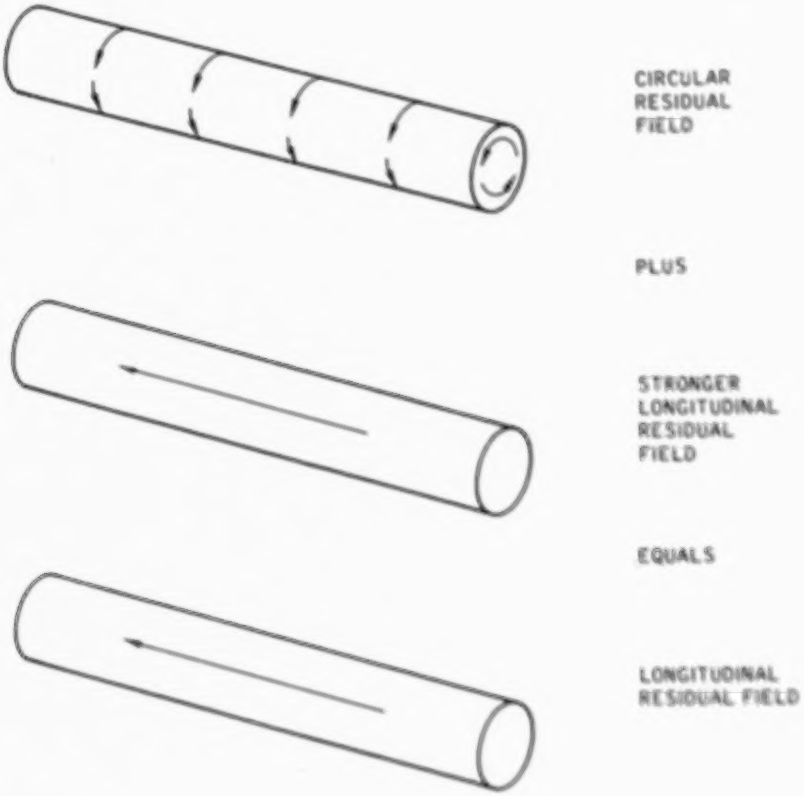
Keep in mind that, in any one article, the strongest magnetizing force will cause the strongest residual field in that article.

Return to page 7-7 and reread the question.

From page 7-7

Right. The original longitudinal magnetizing force was weaker than the original circular magnetizing force.

Here's what happens when the second residual field is as strong as, or stronger than, the first residual field. The second field applied completely overcomes the first field.


CIRCULAR
RESIDUAL
FIELD
PLUS
STRONGER
LONGITUDINAL
RESIDUAL
FIELD
EQUALS
LONGITUDINAL
RESIDUAL FIELD

In this case the original longitudinal magnetizing force must have been as strong as, or ___________ than, the original circular magnetizing force.

stronger . . . . Page 7-10

weaker . . . . Page 7-11

From page 7-9

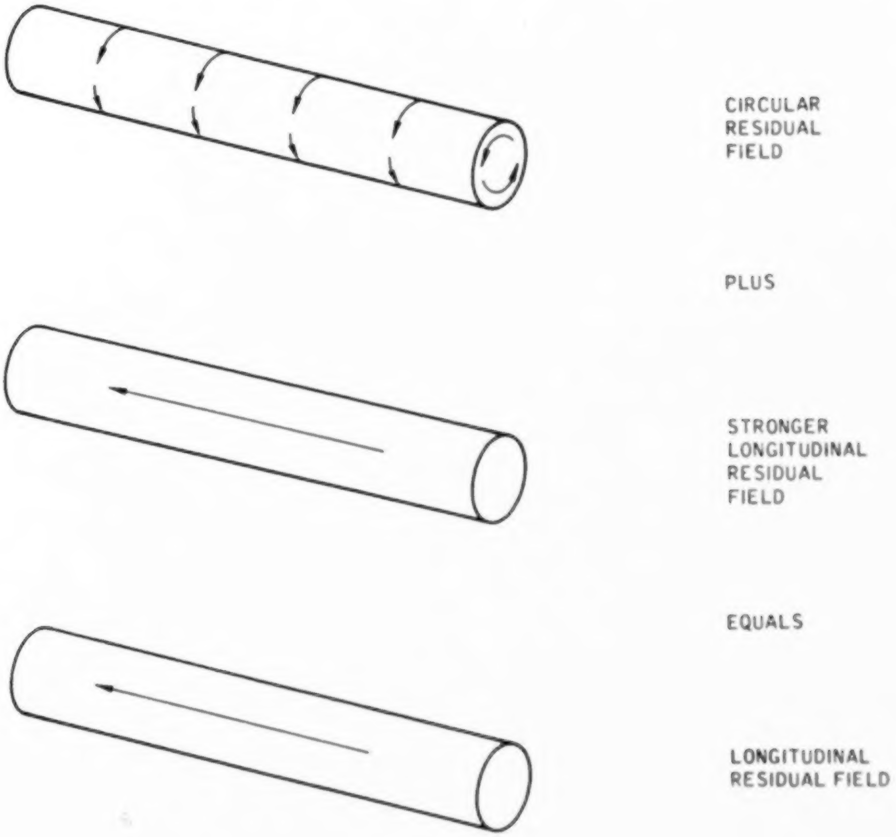
That's right. The original magnetizing force for the longitudinal field must have been as great or greater than the original magnetizing force for the circular field.

If we are going to replace one type of field with another type of field, we must use a magnetizing force as great as, or greater than, the original magnetizing force.

Turn to page 7-12.

From page 7-9

Slow down.

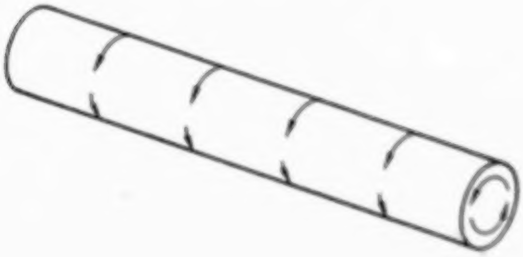

CIRCULAR
RESIDUAL
FIELD
PLUS
STRONGER
LONGITUDINAL
RESIDUAL
FIELD
EQUALS
LONGITUDINAL
RESIDUAL FIELD

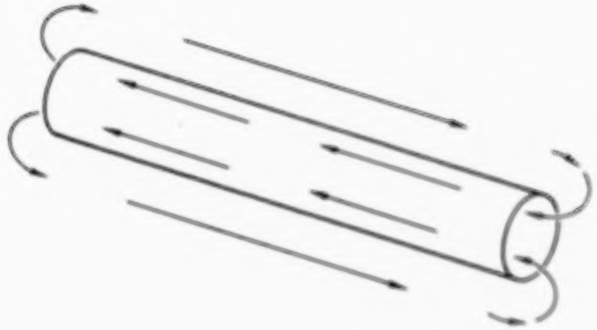
The first field applied was a circular field. The second field applied was a longitudinal field.

The second field applied has to overcome the first field so it must be stronger.

Turn to page 7-12.

From page 7-10





The two bars above show, simply, how the flux lines are entirely contained inside the circularly magnetized bar and how they leave the bar that is longitudinally magnetized.

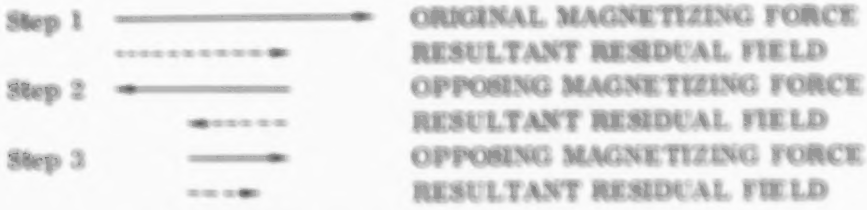
Since the flux lines do not leave the bar that is circularly magnetized, it is very difficult to tell whether the circularly magnetized bar is demagnetized because the flux lines do not normally leave the bar. It is easy to tell whether the longitudinally magnetized bar is magnetized or demagnetized because the flux lines always leave the bar.

If we know that an article has been circularly magnetized, then the best thing to do is to magnetize it longitudinally so that we can be sure it is demagnetized at the end of the demagnetizing procedure.

Turn to page 7-13.

That's right. Once a residual field has been established in the longitudinal direction, we can determine if the article is magnetized and, more important, when it has become demagnetized. We cannot determine this from a circularly magnetized article.

Consider an article that has been longitudinally magnetized. We will now magnetize it in the opposite direction. If we could select the right field strength that would exactly overcome the residual field strength, we would then find that the residual field has been reduced but is now in the opposite direction.


Step 1
ORIGINAL MAGNETIZING FORCE
RESULTANT RESIDUAL FIELD
Step 2
OPPOSING MAGNETIZING FORCE
RESULTANT RESIDUAL FIELD
Step 3
OPPOSING MAGNETIZING FORCE
RESULTANT RESIDUAL FIELD

This diagram gives the clue to the method used to reduce the residual field in an article. Each time the magnetizing field is reversed and reduced, the residual field is

________________.

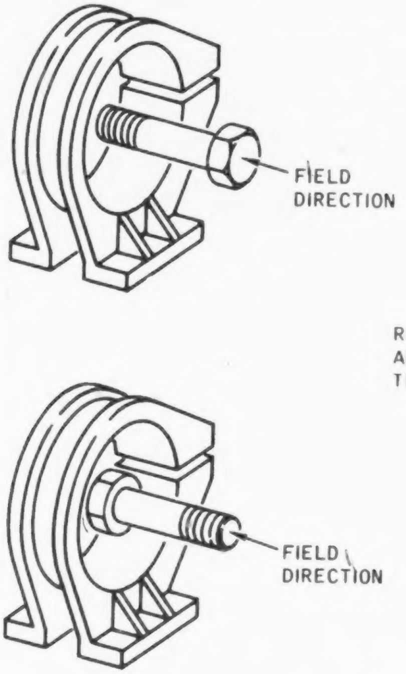
reduced . . . . Page 7-14

increased . . . . Page 7-15

From page 7-13

Right! If the magnetizing field is reversed and reduced in successive steps to zero, the residual field will be reduced to zero.

Reversing and reducing the magnetizing field can be done in several ways. First, let's consider ways in which the magnetizing field in an article may be reversed.



REVERSING THE FIELD IN AN ARTICLE BY REVERSING THE ARTICLE

If an article were being magnetized in a magnetic field, reversing the article in the field would reverse the field in the article. This is easily accomplished with small articles magnetized by a coil.

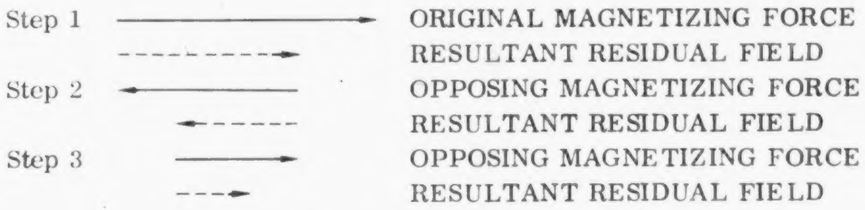
Another way to reverse the field would be to reverse the current through the coil.

True . . . . Page 7-16

False . . . . Page 7-17

From page 7-13

You've missed the point somehow. Here's the diagram again.


Step 1
ORIGINAL MAGNETIZING FORCE
RESULTANT RESIDUAL FIELD
Step 2
OPPOSING MAGNETIZING FORCE
RESULTANT RESIDUAL FIELD
Step 3
OPPOSING MAGNETIZING FORCE
RESULTANT RESIDUAL FIELD

In step one, we show the original magnetizing force. The magnetizing force disappears the instant the current is turned off, but the residual field remains as indicated by the dotted arrow. We then reduce the magnetizing force and reverse its direction (shown in step 2). The resultant residual field is reversed and becomes smaller. In the demagnetization process, the procedure is carried on until the magnetizing force and the residual field disappear.

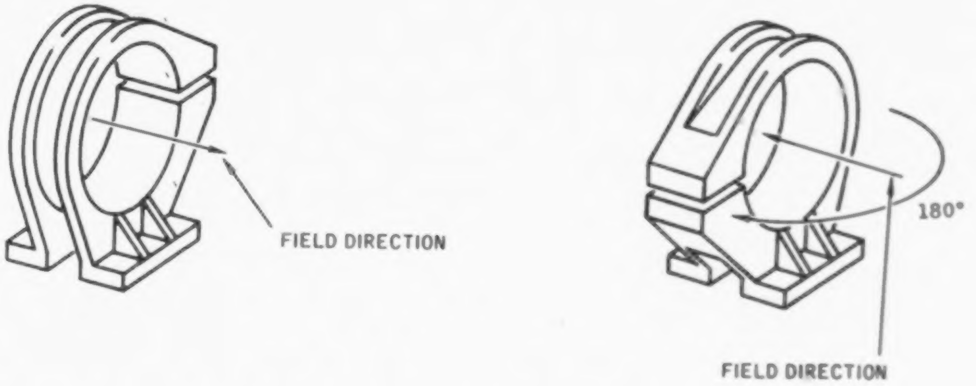
Turn to page 7-14.

From page 7-14

Right! Reversing the current would reverse the magnetic field. Then the magnetic field in an article may be reversed by:

1. Reversing the article in the magnetic field.
2. Reversing the current through the coil.

A third possibility, though not often as practical as the first two, would be to reverse the coil; that is, turn the coil 180°.



REVERSING FIELD DIRECTION BY TURNING THE COIL 180°

Now let's review a little.

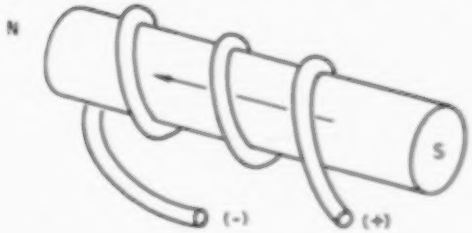
To demagnetize the article, we must reverse the field and_______the field strength.

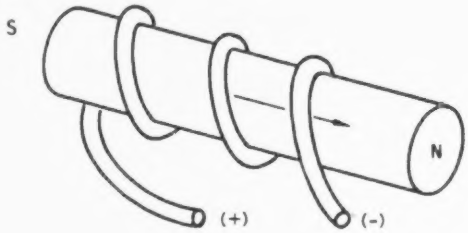
reduce . . . . Page 7-18

increase . . . . Page 7-19

From page 7-14

Stop and think a minute. Remember the right hand rule? Let's apply it to the coil.





Notice that when we reverse the direction of the current through the coil the polarity of the field reverses. This is what we mean by "reversing" the field.

Turn to page 7-16.

From page 7-16

Correct - we must reverse the field and reduce the field strength.

There were three ways to reverse the field. Let's see how many ways there are to reduce the field strength.

Remember that when magnetizing an article, the field strength depended on the current; the higher the magnetizing current, the higher the field strength.

One way to reduce the field strength would be to ____________ the magnetizing current.

reduce . . . . Page 7-20

increase . . . . Page 7-21

You have it backwards. In demagnetizing an article, we want to reduce the residual field. This is accomplished by reducing the field strength and reversing the field.

Turn to page 7-18.

From page 7-18

Right - reducing the magnetizing current reduces the strength of the magnetizing field.

The magnetic field around a coil is strongest within and at the inside diameter of a coil. As the distance from this point increases, the field becomes weaker.

Consider an article that is being magnetized by the use of a coil. The further the article is moved from the coil the______the effect of the magnetizing field on the article.

stronger . . . . Page 7-22

weaker . . . . Page 7-23

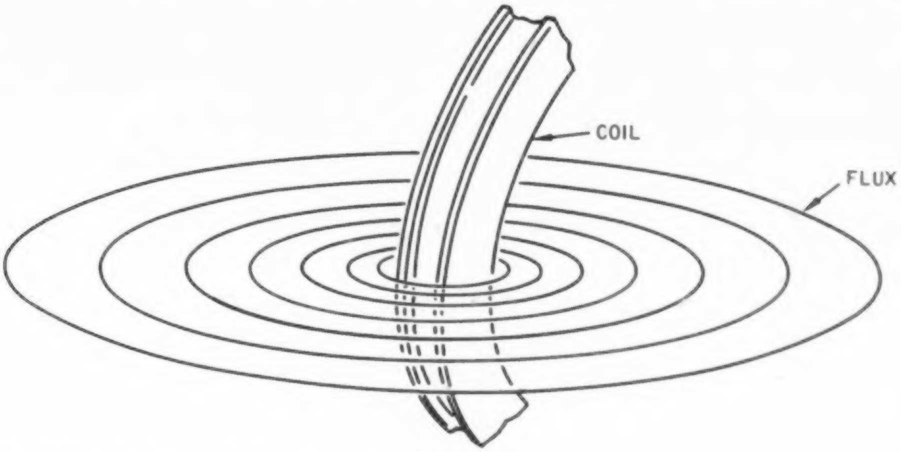
From page 7-18

Think back to the procedures we followed in magnetic inspection. To increase the magnetizing field in an article, we increased the current. To decrease the magnetizing field we decreased, or reduced the current. These rules do not change. They are good for magnetizing or demagnetizing any article.

Turn to page 7-20.

From page 7-20

Here is a side view of part of a coil and part of the magnetizing field set up by a coil.



Notice that close to the coil the flux density is greatest. At greater distances from the coil the flux density becomes less. This means that the magnetizing field strength becomes weaker as the distance from the coil increases.

Turn to page 7-21.

Right - moving the article away from the coil will reduce the strength of the magnetizing field.

Since moving the article away from the coil reduces the strength of the magnetizing field in the article, you could expect that moving the coil_______the article would also reduce the magnetizing field strength.

toward . . . . Page 7-24

away from . . . . Page 7-25

From page 7-23

Perhaps we have confused you. We are talking about the effect of the magnetizing field on the article.

Moving the coil does not affect the magnetizing field of the coil so far as the coil is concerned. But moving the coil away from the article does affect the magnetic field that has been set up in the article.

Turn to page 7-25.

Good! Moving the article away from the coil, or moving the coil away from the article, will weaken the magnetizing field.

We have discussed three ways in which the magnetizing field may be reduced:

1. Reduce the magnetizing current.
2. Move the article away from the coil.
3. Move the coil away from the article.

These three ways to reduce the field, along with the three ways to reverse the field, cover the theory behind demagnetization. Any method of demagnetization will combine one of the methods to reduce the magnetizing field with one of the methods to reverse the magnetizing field.

Demagnetization: The removal of residual magnetism by simultaneously or alternately reducing the strength and reversing the direction of a magnetic field.

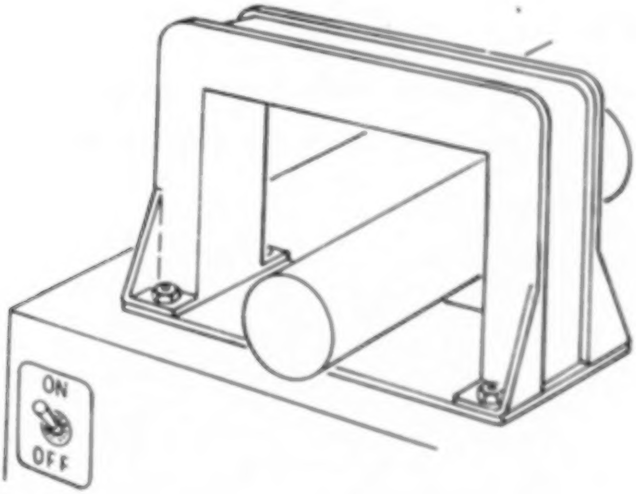
Turn to page 7-26.

From page 7-25

DEMAGNETIZATION PROCEDURES.

Now let's take a look at the more common methods of demagnetization, and see how they fit the theory.

The first method we want to discuss is alternating current coil demagnetization. What is alternating current? Alternating current is electrical current that flows through a wire first in one direction, then in the opposite direction. Normal house current is the best example of alternating current. Normal 60 cycle house current reverses its direction 120 times each second.



Let's connect 60 cycle alternating current to this coil. Each time the current reverses direction, the magnetic field of the coil ______________ .

reverses . . . . Page 7-27

becomes weaker . . . . Page 7-28

Correct. Each time the current reverses direction through the coil, the magnetic field reverses direction. In the case of 60 cycle alternating current, the field reverses direction 120 times per second.

All that we need then to complete the demagnetization of any article placed in this reversing magnetic field would be to slowly reduce the strength of the field.

Which of the procedures listed below would not reduce the strength of the field?

Reduce the current through the coil . . . . Page 7-29

Reverse the coil . . . . Page 7-30

Move the article away from the coil . . . . Page 7-31

From page 7-26

Now why should the magnetic field get weaker when the current reverses? Perhaps you are thinking that the field must reduce to zero before it establishes itself in the opposite direction.

In this sense your answer is right, however, the overall, average field remains the same. It just reverses itself each time the current reverses.

Turn to page 7-27.

Slow down! You have selected an answer that says, "Reducing the current through the coil will not reduce the strength of the field," This is not true. Reducing the current will reduce the strength of the field.

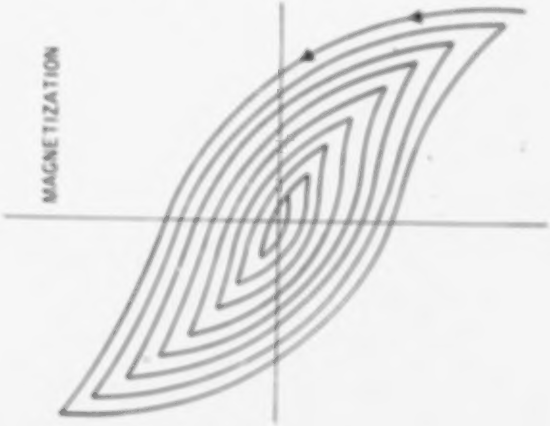
Return to page 7-27 and read the question again.

From page 7-27

Right! Reversing the coil will only reverse the field. It will not reduce the strength of the field.

Let's discuss ways of reducing the field strength when using alternating current through a coil.

Reducing the current through the coil. This can be accomplished by automatic stepping switches. (A stepping switch is a switch with several positions, usually driven by a small motor.) The first step applies maximum current through the coil. As the switch "steps" through its various positions, the current is reduced with each step until it is completely turned off. A stepping switch may also be hand operated, or a device called a rheostat may be used. They all serve the same purpose - reducing the current. The hysteresis loop shows the reduction in current. The center of the loop is the point which represents zero current.



Other methods include using a motor driven, ac generator as a power source. When the motor is turned off, the generator output slowly decreases as the motor coasts to a stop. Other methods are available, but the important thing to remember is that the current starts out at a maximum and is slowly reduced to zero.

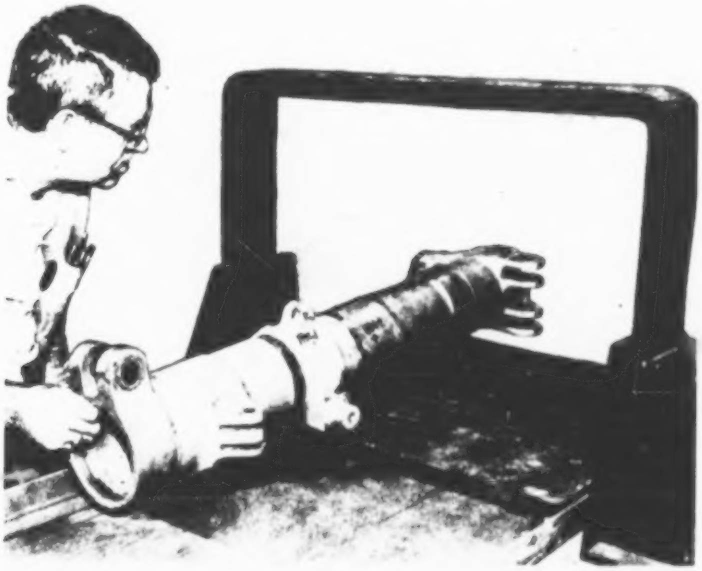
Turn to page 7-32.

Wrong! Moving the article away from the coil reduces the field strength. We were looking for the answer that does not reduce the strength of the field.

Return to page 7-27 and select a better answer.

From page 7-30

Reducing the magnetizing field in an ac coil demagnetizer is most commonly accomplished by moving the article away from the coil. Most ac coil demagnetizers are equipped with carriages or belt conveyors by which the articles are carried through the coil opening and away from the coil.



A-C COIL DEMAGNETIZER WITH CARRIAGE

For extremely large articles, methods are devised whereby the coil is moved down the length of the article. Any point on the article is strongly magnetized as the coil passes over it. As the coil moves down the article, the field strength at that point slowly decreases. Remember that the current should never be turned off while the coil is close to the article since this will leave the article magnetized.

Turn to page 7-33.

From page 7-32

In demagnetizing procedures using alternating current, the field is automatically reversed because the current automatically reverses. It is also possible to demagnetize an article using direct current (dc). When using dc, it is necessary to use some method of reversing the field (usually by reversing the current).

Let's review what you know about ac and dc magnetization processes.

Direct current magnetization is ____________ penetrating than alternating current magnetization.

more . . . . Page 7-34

less . . . . Page 7-35

Right! Direct current magnetization is more penetrating than alternating current magnetization, therefore dc is most useful on large massive articles if more complete demagnetization is required. It has been discovered that the best demagnetization occurs when the field is reversed at a frequency of 1 reversal per second. Since normal alternating current reverses at 60 cycles per second, ac does not give the best possible results in demagnetization. Direct current can be controlled at a 1 cycle-per-second rate and therefore is used when the maximum degree of demagnetization is to be obtained.

When direct current is used in a demagnetizing process, the direction of the current should be reversed ____________________.

60 times per second . . . . Page 7-36
once each second . . . . Page 7-37

From page 7-33

No, dc is more penetrating. Remember how discontinuities below the surface gave better indications when the magnetizing field was produced by direct current. This indicates that the field reaches further into the metal.

Turn to page 7-34.

From page 7-34

You have confused the frequency of alternating current with the frequency at which the best demagnetization is obtained.

We use 60-cycle, alternating current because it is easy to obtain. Almost all commercial power is 60-cycle, alternating current.

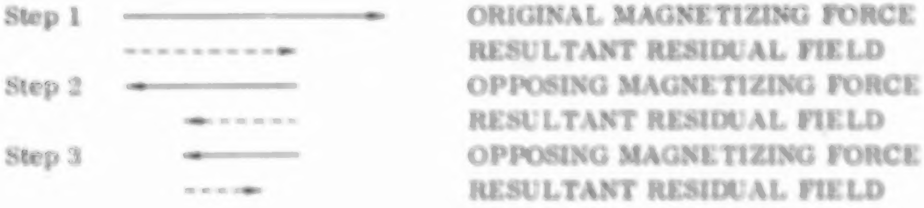
But for demagnetization, we know that 1 cycle per second gives the best results. We can reverse direct current once every second, easily. So if dc is to be used in demagnetizing, the best results are obtained when the direction of the current is reversed once each second.

Turn to page 7-37.

From page 7-34

Right! When demagnetizing with direct current, the current should be reversed at a rate of 1 reversal each second.

Let's look at our demagnetizing chart again.


Step 1
ORIGINAL MAGNETIZING FORCE
RESULTANT RESIDUAL FIELD
Step 2
OPPOSING MAGNETIZING FORCE
RESULTANT RESIDUAL FIELD
Step 3
OPPOSING MAGNETIZING FORCE
RESULTANT RESIDUAL FIELD

This chart shows the magnetizing force being reduced and reversed at the same time. In actual practice, one has to be done before the other. If the magnetizing field were reversed before it was reduced, the resultant field would not be reduced. It would be reversed, but not reduced.

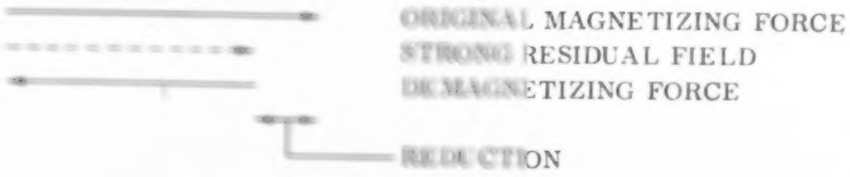
What, in your opinion, would happen to the resultant field if the magnetizing field were reduced then reversed.

The resultant field would be reduced and reversed . . . . Page 7-38

The resultant field would be reduced but not reversed . . . . Page 7-39

Right! The magnetizing field should be reduced first, then reversed.

How many reduction-reversal steps are required when demagnetizing with dc fields? This depends on the permeability of the material. Here's what happens in material with low permeability.


ORIGINAL MAGNETIZING FORCE
STRONG RESIDUAL FIELD
DEMAGNETIZING FORCE
REDUCTION

The demagnetizing force must be as strong or stronger than the residual field. If the demagnetizing force were reduced in large steps, the residual field would not be overcome and, therefore, would not be reduced.

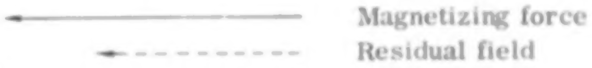
When the permeability of the material is low, the demagnetizing field must be reduced in ____________________ steps.

smaller . . . . Page 7-40
larger . . . . Page 7-41

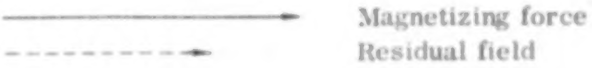
From page 7-37

Keeping "reduce" and "reverse", and which comes first, straight in your mind can be very difficult. Let's look at demagnetization one step at a time.

An article is magnetized whenever it is placed in a magnetizing field. When the article is removed from the magnetizing field, the article is left with a magnetic field of its own called "residual" magnetism. The residual magnetism is in the same direction as the magnetizing force but is much weaker. Let's show this with two lines:

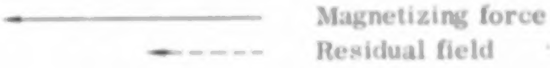

Magnetizing force
Residual field

Now what happens if we reverse the direction of the magnetizing field without reducing it:


Magnetizing force
Residual field

Notice that the residual field was reversed, but it is just as strong as it was in the opposite direction.

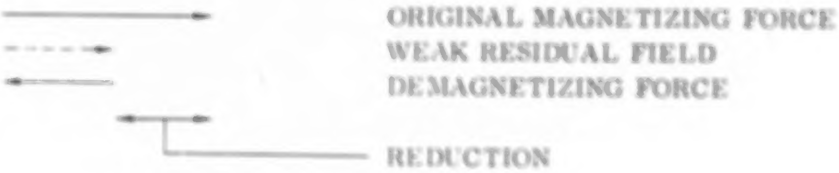
Now let's reduce the magnetizing field and then reverse its direction:


Magnetizing force
Residual field

Notice that now the residual field is reduced as well as reversed.

Turn to page 7-38.

Very good! Low permeability requires smaller steps in the reduction of the demagnetization field. Here's what happens in materials with high permeability.

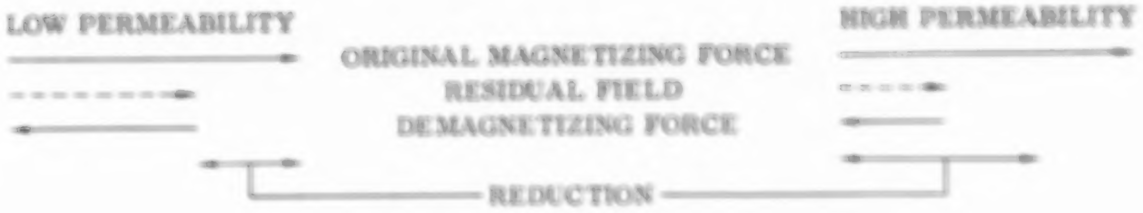

ORIGINAL MAGNETIZING FORCE
WEAK RESIDUAL FIELD
DEMAGNETIZING FORCE
REDUCTION

It follows that material with a high permeability will have a weaker residual field, and the demagnetizing field can be reduced in ______________ steps.

smaller . . . . Page 7-42

larger . . . . Page 7-43

This is a very technical point. Let's look at the charts for two parts with different permeabilities.

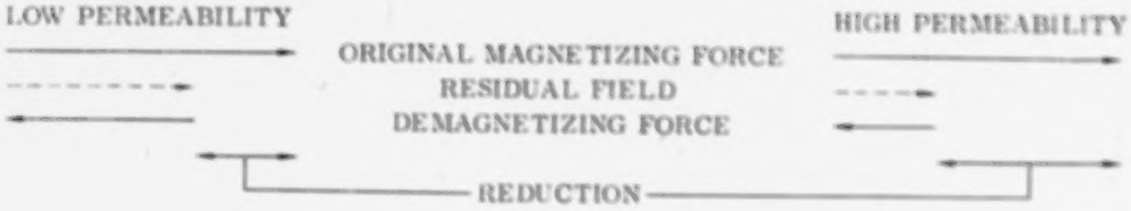

LOW PERMEABILITY
HIGH PERMEABILITY
ORIGINAL MAGNETIZING FORCE
RESIDUAL FIELD
DEMAGNETIZING FORCE
REDUCTION

Compare the strength of the residual fields. The residual field must be overcome by the demagnetizing force. The larger residual field requires a larger demagnetizing field, therefore, the field reduction has to be smaller when the permeability is low.

Turn to page 7-40.

From page 7-40

Let's repeat the charts for material with high permeability and material with low permeability.


LOW PERMEABILITY
HIGH PERMEABILITY
ORIGINAL MAGNETIZING FORCE
RESIDUAL FIELD
DEMAGNETIZING FORCE
REDUCTION

Notice that the residual field for the article with high permeability is much smaller than the residual field for the article with low permeability. It follows, then, that the demagnetizing force for the article with high permeability is much smaller than the demagnetizing force for the article with low permeability. The reduction of the magnetizing force, therefore, is much larger for the article with high permeability.

Turn to page 7-43.

5

Right! With highly permeable material, the demagnetizing force can be reduced in larger steps. This means that fewer steps are required.

With material of low permeability, more steps are required since the reduction is smaller.

As a rule of thumb, at least 10 reversals are required, but not over 30.

When demagnetizing material of very low permeability with direct current, it is likely to require ________ steps.

Less . . . . Page 7-44
More . . . . Page 7-45

From page 7-43

You've got it backwards. Remember this:

Low permeability - strong residual field.
Strong residual field - smaller reduction.
Smaller reduction - more steps.

Material of very low permeability may require as many as 30 steps.

Material of very high permeability may require as few as 10 steps.

Turn to page 7-45.

Right! The material with low permeability will require more steps for demagnetization.

There are a couple of other little tricks that you may run into. We are going to mention them here so that you will recognize them if you ever see them.

The first is tapping the article. Tapping the article with a hammer while the article is in a magnetic field can cause a more favorable distribution of the field. This is rarely done, and then only with pieces that are extremely difficult to demagnetize. The article is never tapped with enough force to damage it.

You may never notice the second trick unless you are looking for it. Any ferromagnetic material is affected by the earth's field which runs in a north-south direction. When an article is demagnetized, the earth's field will leave a small amount of residual magnetism in the article if the demagnetizing field is also in a north-south direction. In very rare cases, where absolute complete demagnetization is required, the demagnetization field must be placed in an east-west direction. That is, the coil openings should face east and west.

There are some other methods of demagnetizing that are used occasionally that we will not cover here. These are usually special applications of particular magnetizing equipment. The thing to remember is that they all follow the reduce-reverse rule when being used for demagnetization.

Turn to page 7-46.

From page 7-45

1. Now let's review, briefly, the rules and procedures for demagnetization.

   If the article was circularly magnetized, the first step in demagnetization is to establish a________________field in the article.

3. reduce
   reverse

4. The best results are obtained when demagnetizing with direct current if the field is reversed at a rate of _________ times each second.

6. 30 - 10

7. When demagnetizing with alternating current, the field direction is reversed _________________________.

9. reducing

10. Turn to page 7-49.

1. longitudinal

2. In order to replace a circular field in an article with a longitudinal field, the longitudinal magnetizing force must be as great or greater than the original ________________ .

4. 1

5. When demagnetizing with direct current, an article with low permeability will require______________reversals than an article with high permeability.

7. automatically - (120 times per second)

8. With ac demagnetization, the field strength is usually reduced by moving the article _______ __________ the coil.

2. magnetizing force

3. Once a longitudinal field has been established in the article, we ________ the field strength and ______________ its direction.

Return to page 7-46, frame 4.

5. more

6. An article with low permeability may require as many as______reversals, while an article with high permeability may require only________reversals.

Return to page 7-46, frame 7.

8. away from

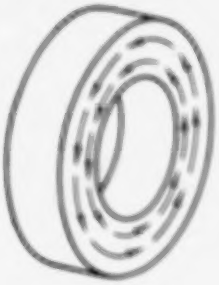
9. With either type of current, the field strength may be reduced by __________ the current.

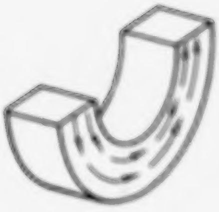
Return to page 7-46, frame 10.

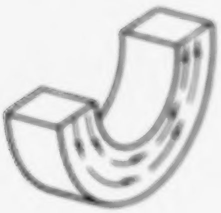
From page 7-46

LEAKAGE FIELD INDICATORS

At the present time there is no known method by which we are able to measure the magnetic field at any given point inside the article without destroying the article. Take, for example, a ring that is circularly magnetized. There is no flux leakage to indicate that the piece is magnetized.





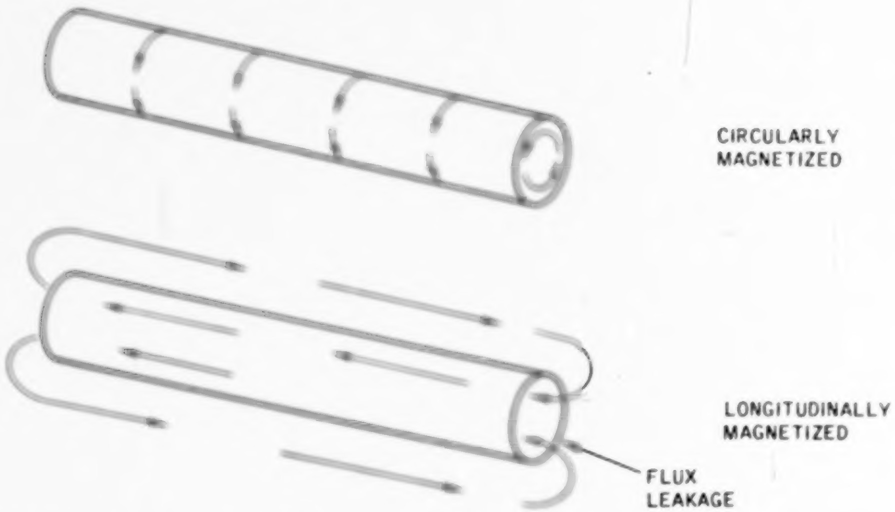


If we cut the ring in half as shown, we can measure the strength of the magnetic field at the cut surfaces where the magnetic field leaves the article. This, however, destroys the usefulness of the article.

In order to tell whether an article is magnetized, we must have ____.

flux leakage from the article . . . . Page 7-50
a circularly magnetized article . . . . Page 7-51

Good! We must have flux leakage in order to determine whether the article is magnetized. This means that longitudinal fields are much easier to detect since there will be flux leakage at both ends of the article.



In practice, we can obtain an indication of flux leakage with an instrument called a field indicator. The field indicator compares the strength of the external field of the article with a fixed field inside the indicator. When the indicator is placed close to any flux leakage, the indicator will show the comparative strength of the two fields.

The field indicator is used more to locate flux leakage than to measure the field strength.

The field indicator is useful in locating any ________ magnetic fields that may exist.

internal . . . . Page 7-52

external . . . . Page 7-53

From page 7-49

We have confused you. A circularly magnetized article may have leakage fields alright; and, if it does, we can tell that it is magnetized. The only way we can tell whether any article is magnetized is to locate any flux leakage from the article.

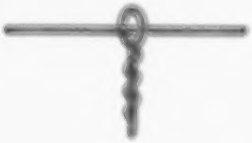
Turn to page 7-50.

Wrong! We cannot tell anything about the internal field of any article. Even if we cut it, we can only tell what is on the cut surface; the internal field of the uncut article still cannot be measured. The field indicator can only indicate external fields.

Turn to page 7-53.

Very good! The field indicator is most useful in locating external magnetic fields. Whenever we want to be sure that an article is demagnetized, we use the field indicator.

Another, more common, method used is a simple piece of iron or steel wire suspended by a loop from another wire.



As the article is brought past this hanging wire, any leakage fields will attract the wire, and it will move. Strong fields will attract the wire more strongly than weak fields. It is very important that this wire does not become magnetized itself.

The hanging wire, shown above, could also be called a field indicator.

True . . . . Page 7-54

False . . . . Page 7-55

Right! The hanging wire is an excellent field indicator. Small pieces of wire are sometimes used to indicate external leakage fields. The bits of wire are laid on a non-magnetic surface and the article is placed on top of the wire. If the wires lift as the article is lifted, then excessive leakage fields exist. Care must be taken to see that the wires do not become magnetized.

The field indicators we have mentioned are generally used to check on the effectiveness of the demagnetization procedure.

Turn to page 7-56.

Think about it for a moment. Does it accomplish the same things as a field indicator? Does it detect external fields? Does it indicate to some degree the strength of the external field? Since the answer to all these questions is "yes," the wire is a field indicator.

Turn to page 7-54.

From page 7-54

You have just completed the programmed instruction course of Magnetic Particle Testing.

Now you may want to evaluate your knowledge of the material presented in this handbook. A set of self-test questions are included at the back of this book. The answers can be found at the end of the test.

We want to emphasize that the test is for your own evaluation of your knowledge of the subject. If you elect to take the test, be honest with yourself - don't refer to the answers until you have finished. Then you will have a meaningful measure of your knowledge.

Since it is a self evaluation, there is no grade - no passing score. If you find that you have trouble in some part of the test, it is up to you to review the material until you are satisfied that you know it.

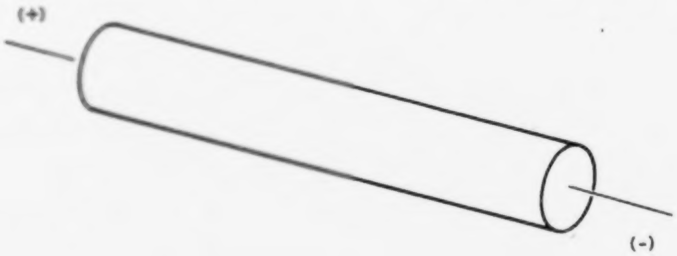
Rotate the book 180° and flip to page T-1 at the back of the book.

MAGNETIC PARTICLE TESTING

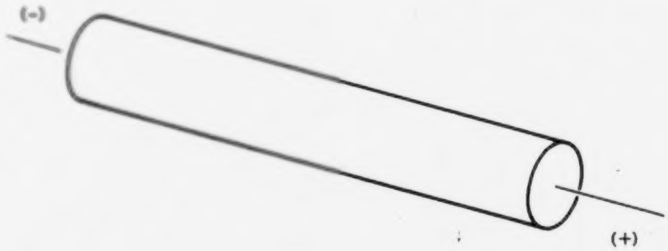
Self-Test

1. Which of the following correctly states the magnetic law of attraction?
   a. Like poles attract each other — opposite poles repel each other.
   b. Like poles repel each other — opposite poles attract each other.

2. In what direction is the electric current flowing through this round steel bar? Indicate by arrows.



3. With arrows, indicate the direction of the magnetic field in this round steel bar. (Presume that electric current is flowing through the bar.)



Below are listed some terms and definitions. Place the letter of each definition in the blank space alongside the term to which it applies.

TERMS

4. Coercive force
5. Residual magnetism
6. Reluctance
7. Flux density
8. Permeability
9. Retentivity

DEFINITIONS

a. THE EASE WITH WHICH MATERIALS CAN BE MAGNETIZED.

b. THE ABILITY OF MATERIAL TO RETAIN A CERTAIN AMOUNT OF RESIDUAL MAGNETISM.

c. THE MAGNETIC FIELD WHICH REMAINS IN A MATERIAL AFTER THE MAGNETIZING FORCE IS REMOVED.

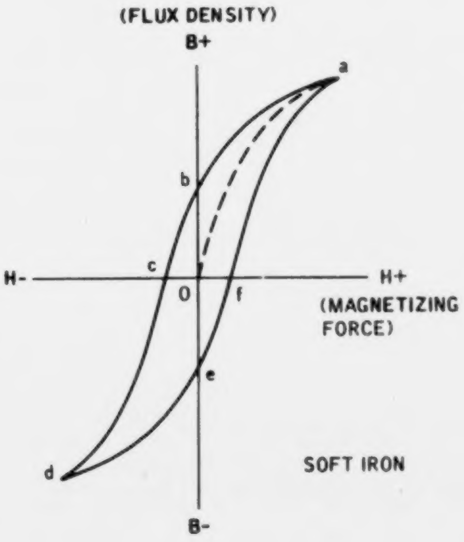
d. THE REVERSE MAGNETIZING FORCE REQUIRED TO REMOVE THE RESIDUAL MAGNETISM FROM THE MATERIAL.

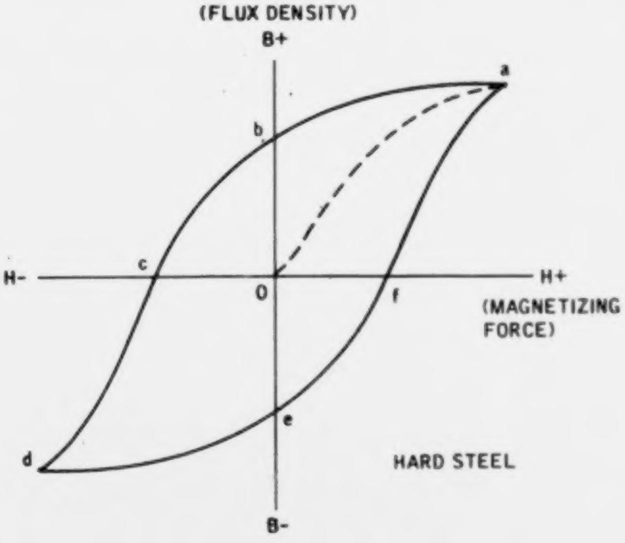
e. THE RESISTANCE OF A MATERIAL TO A MAGNETIZING FORCE.

f. THE NUMBER OF LINES OF FORCE PER UNIT AREA.

Continued on page T-3

Below are two hysteresis loops--one for soft iron and one for hard steel. Analyze each loop and fill in the blank spaces of the five items below each loop with "high" or "low."


(FLUX DENSITY)
B+
a
b
c
H-
0
f
H+
(MAGNETIZING FORCE)
e
d
SOFT IRON
B-


(FLUX DENSITY)
B+
a
b
c
H-
0
f
H+
(MAGNETIZING FORCE)
e
d
HARD STEEL
B-

This loop shows (high or low):

10. _______ permeability

11. _______ retentivity

12. _______ coercive force

13. _______ reluctance

14. _______ residual magnetism

This loop shows (high or low):

15. _______ permeability

16. _______ retentivity

17. _______ coercive force

18. _______ reluctance

19. _______ residual magnetism

20. Longitudinal magnetization can be established in an article by:

    a. Passing current through a central conductor
    b. Placing the part inside a coil through which current is flowing
    c. Passing current through the length of the article

21. The two primary methods of inducing circular magnetism in an article are:

    a. With a coil and with a central conductor
    b. With a central conductor and by placing the article between the heads
    c. With a central conductor and by use of a yoke

22. When a hollow tubular part is magnetized between the heads, flux density will be greatest:

    a. At the inside surface (I. D.)
    b. At the center of the hole in the article
    c. At the outside surface

23. When using a central conductor to magnetize a hollow article, flux density in the article will be greatest:

    a. At the outside surface of the article
    b. At the inside surface of the article
    c. Neither of the above

24. What is an advantage of using a central conductor to magnetize articles?

    a. Detection of cracks on the outside surface of hollow articles
    b. Detection of cracks on the inside surface of hollow articles
    c. Neither of the above

25. The strength of the magnetic field in a coil is determined by:

    a. The current in the coil
    b. The number of turns in the coil
    c. Both of the above

26. An article has been circularly magnetized and retains a circular residual field. To replace the circular field with a longitudinal field, we longitudinally magnetize the article with a field that is as great or greater than:

    a. The circular residual field
    b. The original magnetizing circular field
    c. The longitudinal residual field

27. Whenever an article has been circularly magnetized, the first step in the demagnetization procedures is to establish:

    a. A longitudinal field in the article
    b. A circular field in the article
    c. A residual field in the article

28. When a round steel bar is magnetized by passing current through its length, flux density is:

    a. Greatest along its center line
    b. Greatest at the surface
    c. Uniform throughout its cross section
    d. Greatest at the ends of the material

29. In magnetic particle testing, circular magnetization is obtained by:

    a. Placing test articles within a current-carrying coil
    b. Passing current directly through the length of the article
    c. Using a yoke magnet with poles displaced along length of article

30. In dry magnetic particle testing, best results are obtained when the magnetic field from prods is applied:

    a. Along the length of the discontinuity
    b. In a direction crosswise to the direction in which the discontinuity lies
    c. So that the magnetic field parallels the direction of the discontinuity
    d. None of the above

31. Surface seams in rolled bars are best detected in magnetic particle testing with:

    a. Longitudinal magnetization
    b. Circular magnetization
    c. Prod magnetization
    d. Yoke magnetization

32. 60 cycle alternating current tends to flow through an article:

    a. Evenly throughout the cross section of the article
    b. Near the surface of the article
    c. Near the inside surface of a hollow article

33. Which type of electric current is best for detecting subsurface discontinuities?

    a. Direct current
    b. Halfwave dc
    c. Alternating current

34. Which type of current is best for detection of surface discontinuities?

    a. Direct current
    b. Halfwave dc
    c. Alternating current

35. Alternating current can be used to locate subsurface discontinuities. (True - False) __________ .

36. Whether using ac or dc, which type of magnetic particles provides the greatest sensitivity?

    a. Dry magnetic particles
    b. Particles used in the wet bath method

37. Which method is most effective for locating deep subsurface discontinuities?

    a. Straight dc with dry powder
    b. AC with dry powder
    c. HWDC with dry powder

38. A test object 10 inches long and 2 inches in diameter, longitudinally magnetized in a 5-turn coil, requires a magnetizing current of:

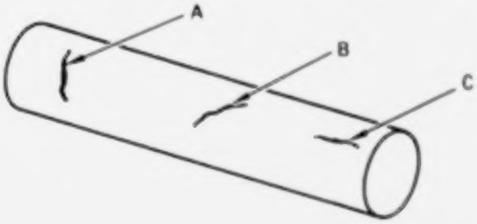
    a. 600 amperes
    b. 1200 amperes
    c. 1800 amperes
    d. 2400 amperes

39. When using a coil, what is the effective distance of the magnetic field?

a. 6 to 9 inches on each side of the coil
b. 18 inches on each side of the coil
c. 6 to 9 inches

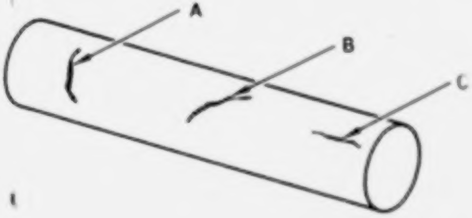
40. Which cracks in this round bar can be detected by longitudinal magnetization?

_________ A
_________ A and B
_________ B and C
_________ A and C



41. Which cracks in this round bar can be detected by circular magnetization?

_________ A
_________ A and B
_________ B and C
_________ A and C



Insert in the blank after each letter, the best magnetizing method of locating each discontinuity. (Example: circular between the heads, circular with central conductor, or longitudinal in coil.)

42. A _______________________

43. B _______________________

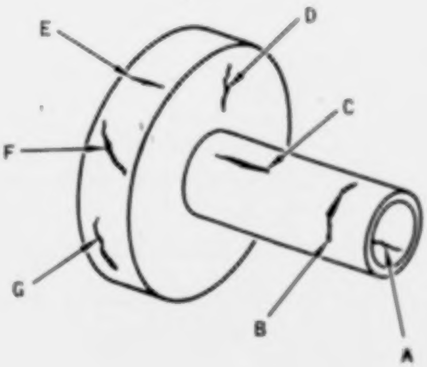
44. C _______________________

45. D _______________________

46. E _______________________

47. F _______________________

48. G _______________________



49. How much current would be required to circularly magnetize an article 10 inches long and 2 inches in diameter?

a. 2400 to 3200 amperes
b. 1800 to 2400 amperes
c. 1200 to 1600 amperes
d. 600 to 800 amperes

50. To obtain best results when using prods, what should be the distance between prods?

a. 5 to 10 inches
b. 6 to 8 inches
c. 12 to 16 inches
d. 4 to 6 inches

51. How many coil shots would be required to adequately magnetize a bar 24 inches long? ____________________ .

52. Flux density is greatest at what point on a coil?

a. At the center of the coil
b. Near the inside surface of the coil
c. Outside the coil

53. If an article is being magnetized between the heads, where is the flux density greatest?

a. In the center of the article
b. Outside the article
c. At the surface of the article

54. When magnetizing with a central conductor, flux density is greatest where?

a. At the surface of the conductor
b. Outside the conductor
c. Near the outside surface of the article being magnetized

55. In what way should dry magnetic particles be applied to a magnetized area?

a. Poured on the area
b. Allowed to drift to the area in a light cloud
c. Blown forcibly at the area

56. When using the wet residual method, the liquid bath is applied to the article at which of the following times?

a. Immediately before magnetizing shot
b. During magnetizing shot
c. After magnetizing shot

57. The residual method of testing could be expected to give best test results on material with which of the following qualities?

a. Low permeability
b. High permeability

58. With the wet continuous method, the liquid bath is applied at which of the following times?

a. After magnetizing shot
b. Immediately before magnetizing shot
c. During magnetizing shot

59. With the dry continuous method, the powder particles are applied at which of the following times?

a. During magnetizing
b. After magnetizing
c. Before magnetizing

60. Nonrelevant indications are caused when magnetic particles are attracted to leakage fields which occur from:

a. Discontinuities such as seams and nonmetallic inclusions
b. Accumulations of magnetic particles that are held mechanically or by force of gravity
c. Causes other than true discontinuities

61. The most frequent cause for nonrelevant indications is:

a. Using the wrong type of magnetizing current
b. Using excessive magnetizing current
c. Using a small amount of magnetizing current

62. What is usually the distinctive feature of nonrelevant indications?

a. They are sharp and clearly defined
b. They disappear very quickly
c. They are fuzzy and not clearly defined

63. If a hard piece of steel is welded to a soft piece of steel, a nonrelevant indication would appear at the weld. What would be the cause for the nonrelevant indication?

a. A defective weld
b. Difference of permeability in the materials
c. Structural design of the article

64. Why is it important that nonrelevant indications be recognized and eliminated?

a. They may mask true indications of discontinuities
b. They may mask false indications of discontinuities
c. They may mask indications of magnetic writing

65. When a magnetized article is touched by another piece of ferromagnetic material, the magnetic field in the magnetized part is:

a. Strengthened
b. Distorted
c. Straightened

66. When two pieces of steel rub against each other and either or both are in a magnetized condition, an indication is sometimes formed when magnetic particles are applied. This type of indication is called:

a. Cold working
b. Construction
c. Magnetic writing
d. False indication

67. Indications caused by leakage fields due to internal splines, keyways, etc., are called:

a. Magnetic writing
b. Nonrelevant indications
c. Indications of discontinuities

68. Occasionally, indications are caused when magnetic particles are accumulated and held mechanically or by gravity in surface irregularities. These indications are not formed by leakage fields. This type of indication is called:

a. A nonrelevant indication
b. A false indication
c. Magnetic writing

69. A residual magnetic field is always:

a. Stronger than the magnetizing field producing it
b. Weaker than the magnetizing field producing it
c. Equal to the magnetizing field producing it

70. The flux density of a demagnetizer coil is greatest near the inside wall of the coil. (True - False)____________.

71. When magnetizing with the central conductor, how many amperes would be required to circularly magnetize a hollow tube with an outside diameter of 2 inches?

a. 300 to 400 amperes
b. 600 to 800 amperes
c. 1200 to 1600 amperes
d. 200 to 400 amperes

72. When demagnetizing an article in a dc coil, the magnetizing current should never be turned off while the article is in the coil. (True - False)______________.

73. Magnetic particle indications are caused when magnetic particles are attracted at which of the following?

a. Flux leakage
b. Magnetic poles
c. Leakage fields
d. All of the above

74. If an article is to be magnetized longitudinally after it has been circularly magnetized, is it necessary to demagnetize between magnetization shots? (Yes - No)________.

75. Magnetic particle testing will not usually detect subsurface discontinuities located:

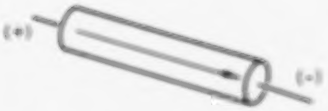
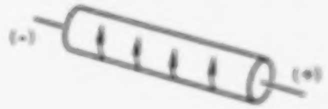
a. Within 1/4 of an inch from the surface
b. At a depth greater than 1/4 of an inch from the surface
c. At any depth below the surface

76. Best results are obtained during dc demagnetization when the current is reversed at a rate of__________times each second.

77. Which of the following is the general procedure followed when demagnetizing an article?

a. Reverse the field then reduce the field strength
b. Reduce the field strength then reverse the field

ANSWERS TO SELF-TEST

		Page No. Ref.
1.	b	1-2
2.		2-9
3.		2-1
4.	d	1-53
5.	c	1-40
6.	e	1-61
7.	f	1-46
8.	a	1-39
9.	b	1-50
10.	high	1-65
11.	low	1-65
12.	low	1-65
13.	low	1-65
14.	low	1-65
15.	low	1-63
16.	high	1-63
17.	high	1-63
18.	high	1-63
19.	high	1-63
20.	b	2-55
21.	b	2-10
22.	c	2-39
23.	b	2-44
24.	b	2-44

	Page No. Ref.
25. c	3-37
26. b	7-9
27. a	7-12
28. b	3-11
29. b	2-10
30. b	2-75
31. b	2-24
32. b	3-1
33. b	3-6
34. c	3-1
35. False	3-1
36. a	4-9
37. c	4-23
38. c	3-37
39. a	3-39
40. A and B	2-57
41. B and C	2-17
42. Circular with central conductor	2-44
43. Longitudinal in coil	2-57
44. Circular, between heads or central conductor	2-44
45. Circular, between heads or central conductor	2-46
46. Circular, between heads or central conductor	2-44
47. Longitudinal in coil, or circular between heads	2-17
48. Longitudinal in coil	2-17

		Page No. Ref.
49.	c	3-24
50.	b	2-78
51.	2	3-39
52.	b	2-56
53.	c	2-30
54.	a	2-44
55.	b	4-9
56.	c	6-14
57.	a	1-40
58.	b	6-7
59.	a	6-8
60.	c	5-23
61.	b	5-29
62.	c	5-29
63.	b	5-41
64.	a	5-51
65.	b	5-48
66.	c	5-49
67.	b	5-27
68.	b	5-52
69.	b	7-2
70.	True	2-56
71.	c	3-33
72.	True	7-32
73.	d	1-22
74.	No	7-1
75	b	6-23
76.	1	7-34
77.	b	7-37

☆U. S. G.P.O.:1972 – 745-384/4081 Region No. 4